DEVELOPMENT OF NEW METHODOLOGIES FOR EVALUATING THE ENERGY PERFORMANCE OF NEW COMMERCIAL BUILDINGS

A Dissertation

by

SUWON SONG

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2006

Major Subject: Architecture

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Approved by:

Chair of Committee, Jeff S. Haberl
Committee Members, Charles H. Culp
Liliana O. Beltran
William D. Turner
Head of Department, Mardelle Shepley

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ABSTRACT

Development of New Methodologies for Evaluating the Energy Performance of New Commercial Buildings. (August 2006)

Suwon Song, B.S., SungKyunKwan University;
M.S., SungKyunKWan University

Chair of Advisory Committee: Dr. Jeff S. Haberl

During the past decade, utility companies and others have offered new construction programs to promote energy savings based on energy-efficient design, which maximize design flexibility as well as energy savings. For such programs, the concept of Measurement and Verification (M&V) of a new building continues to become more important because efficient design alone is often not sufficient to deliver an efficient building. Simulation models that are calibrated to measured data can be used to evaluate the energy performance of new buildings if it is compared to energy baselines such as similar buildings, energy codes, and design standards (IPMVP 2003; Torcellini et. 2004). Unfortunately, there is a lack of detailed M&V methods and analysis methods to measure energy savings from new buildings that would have hypothetical energy baselines. In addition, many important questions remain, for example: how to simulate and calibrate a simulation with measured data, how to develop energy baselines for comparison to the new building, and how to calculate energy savings compared to energy baselines.

Therefore, this study developed and demonstrated several methodologies for evaluating the energy performance of new commercial buildings using a case-study building in Austin, Texas, in terms of: 1) Whole-building energy metering with in-situ measurements, 2) Simulation and calibration methods applicable to new buildings, and 3) Building energy baselines and savings assessments. Consequently, three new M&V methods were developed in this study to enhance the generic M&V framework (IPMVP 2003) for new buildings, including: 1) The development of a procedure to synthesize weather-normalized cooling energy use (i.e., Btu cooling production) from a correlation of MCC electricity use when chilled

water use is unavailable, 2) The development of an improved method to analyze measured solar transmittance against incidence angle for sample glazing using different solar sensor types, including an Eppley PSP and Li-Cor sensor, and 3) The development of an improved method to analyze chiller efficiency and operation at part-load conditions. Second, three new methods were also developed and analyzed in the process of the as-built model simulation and calibration, including: 1) A new percentile analysis to the previous signature method (Wei et al. 1998) for use with a DOE-2 calibration, 2) A new analysis to account for undocumented exhaust air in DOE-2 calibration, and 3) An analysis of the impact of synthesized direct normal solar radiation using the Erbs correlation (Duffie and Beckman 1991) on DOE-2 simulation. Third, an analysis of the actual energy savings compared to three different energy baselines was performed, including: 1) Energy Use Index (EUI) comparisons with sub-metered data, 2) New comparisons against Standards 90.1-1989 and 90.1-2001, and 3) A new evaluation of the performance of selected ECDMs. Finally, potential energy savings were also simulated from selected improvements, including minimum supply air flow, undocumented exhaust air, and daylighting.

As a result, the calibrated models were determined to have an overall 20.38% CV(RMSE) and a 0.63% MBE for the 2001 model and an overall 23.82% CV(RMSE) and a 0.61% MBE for the 2004 model, which compares well with the previous research (Kreider and Haberl 1994; Bou-Saada 1994; ASHRAE 2002). It was found that the end-use EUIs, such as cooling, heating, and Motor Control Center (MCC) electricity use can begin to provide information about the building's heating and cooling efficiencies compared to similar buildings in a control groups. It was also determined that the REJ building is 20.79% more efficient than the Standard 90.1-1989 and approximately equal to the Standard 90.1-2001. Using an ECDM-subtraction method, the REJ building was shown to use approximately 67% less energy than the base-case building without the ECDMs. Potential savings were simulated to be 7,053.3 MMBtu (19.26%) from the combined improvements when compared to the 2004 as-built simulation.

DEDICATION

To

My Loving Wife and Children

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CHAPTER I

INTRODUCTION

1.1 Background

During the past decade, utility companies and others have offered new construction programs to promote energy savings based on energy-efficient design, which maximize design flexibility as well as energy savings. For such programs, the concept of Measurement and Verification (M&V) continues to become more important because efficient design alone is often not sufficient to deliver an efficient building. The International Performance Measurement & Verification Protocol (IPMVP 2001, 2003), ASHRAE's Guideline 14-2002 (ASHRAE 2002), and the Federal Energy Management Program (Schiller Associates 2000) contain M&V methods for existing building retrofits and selected M&V approaches for new buildings. In addition, several studies have reported on the effectiveness of efforts to improve energy efficiency of new commercial buildings (Diamond et al. 1990, 1992; Kaplan et al. 1992; Peterson and Eley 1996; Brohard et al. 1998; Case and Wingerden 1998; Stein et al. 2000; Torcellini et al. 2004). In 1995, the U.S. Green Building Council (USGBC) developed the Leadership in Energy & Environmental Design (LEED) program in response to the U.S. market's demand for a definition of "green buildings" (USGBC 2002). The LEED program requires the user to demonstrate building energy performance levels consistent with the ASHRAE Standard 90.1-1999 (ASHRAE 1999), or other equivalent local energy codes. Unfortunately, there is a lack of detailed measurement and verification methods to measure energy savings from newly constructed buildings that utilize Energy Conservation Design Measures (ECDMs).

1.2 Problem Statement

The energy performance of a new building can be evaluated with whole-building energy simulation programs such as DOE-2.1e (LBNL 2002), eQUEST(Hirsch 2003), BLAST (BSO 1993), and EnergyPlus (DOE 2001) since these programs offer greater capability for simulating a wide range of design features. Furthermore, certain aspects of such programs have been validated for accuracy and consistency (Neymark and Judkoff 1998, 2002). Simulation models that are calibrated to measured data can be used to evaluate the energy performance of a new building if it is compared to an energy baseline such as a similar building, energy codes, or standards. However, the reliability of energy simulation results is frequently compromised by a lack of certainty that the simulation reflects the actual conditions (Sylvester et al. 2002). In addition, many important questions remain, for example: How do we simulate and calibrate a simulation with measured data? How do we develop energy baselines for comparison to the new building? How do we calculate energy savings compared to energy baselines? Therefore, methods to resolve these issues need to be further studied and demonstrated for the performance evaluation of new buildings.

1.3 Purpose and Objectives

The purpose of this research is to develop and test methodologies for the performance evaluation of new commercial buildings using calibrated simulation. The main objectives of this research are: 1) To develop improved M&V Methods with in-situ measurements for new buildings, 2) To analyze and develop simulation and calibration methods applicable to new commercial buildings, which utilize Energy Conservation Design Measures (ECDMs) (i.e., high performance windows and energy efficient equipment), 3) To develop and compare different energy use baselines, such as a code-compliant baseline with ASHRAE Standard 90.1-1989 (ASHRAE, 1989) vs. Standard 90.1-2001 (ASHRAE, 2001), a design condition without ECDMs, and reference buildings in a control group, and 4) To demonstrate the proposed procedures using a case-study building.

1.4 Organization of the Dissertation

This chapter has introduced the research background, the problem statements, and the purpose and objectives of the research. Chapter II reviews the previous research related to this research, including: energy efficient programs for new buildings, measurement and verification methods, building energy simulation and calibration, and building energy baselines.

Chapter III discusses the significance of the study and the scope and limitations of the research.

This dissertation follows the format of *ASHRAE Transactions.*

Chapter IV discusses the application of the methodology to the case study building used for this research. The methodology in this research contains seven Sections, including: 1) A description of the case study building, 2) Energy Measurement and Verification (M&V), 3) Baselines for building energy use, 4) Energy metering and in-situ measurements, 5) As-built simulation and calibration, and 6) Summary of the methodology.

Chapter V discusses the measured data from the case study building. Utility bills are first analyzed, followed by the 2001 and 2004 measured energy data, which are compared to determine how much the energy consumption data shift during the periods. The results from in-situ measurement for specific building components are also described in this Chapter.

Chapter VI describes development of the as-built simulation model and the results of the calibrated simulation of the case study building for calibrations to both the 2001 and 2004 measured data. The processes of the model calibration are also discussed in terms of the most significant calibration factors in each step.

Chapter VII discusses the comparison of the measured energy use to the ASHRAE 90.1-1989 and 90.1-2001 energy code baselines. Savings from Energy Conservation Design Measures (ECDMs) are also discussed in terms of whole-building and component energy performance.

Chapter VIII discusses energy savings potential from proposed improvements, including: minimum supply air flow rate, duct air loss, and daylighting.

Finally, Chapter IX summarizes this research and discusses the conclusions and recommendations for the future work in this area.

CHAPTER II

LITERATURE REVIEW

In order to develop this study, four categories of the existing literature have been reviewed, including: (1) energy efficient programs for new buildings, (2) Measurement and Verification (M&V) methods, (3) building energy baselines, and (4) building energy simulation and calibration. To accomplish this review, a number of sources have been examined, including: ASHRAE publications, the Journal of Solar Energy Engineering, the Energy and Buildings Journal; the Proceedings of the American Council for an Energy Efficient Economy (ACEEE), the Proceedings of the International Building Performance Simulation Association (IBPSA), the Proceedings of the Symposium on Improving Building Systems in Hot and Humid Climates, and the International Conference for Enhanced Building Operation (ICEBO); reports from nationally-recognized laboratories, including: the Lawrence Berkeley National Laboratory (LBNL), the National Renewable Energy Laboratory (NREL), the Oak Ridge National Laboratory (ORNL), the Energy System Laboratory (ESL) at Texas A&M University; publications from the Federal Energy Management Programs (FEMP), the International Performance Measurement and Verification Protocols (IPMVP), the U.S. Green Building Council (USGBC) publications, the Energy Information Administration (EIA) publications, and other books related to this study.

2.1 Energy Efficiency Programs for New Buildings

Several performance-based energy efficiency programs were reviewed in terms of their energy performance evaluations and effectiveness to improve building energy efficiency, including: the Energy Edge Program in the Pacific Northwest (Diamond et al. 1990, 1992; Kaplan 1992), the Advanced Customer Technology Test for Maximum Energy Efficiency (ACT^2) program (Elberling and Bourne, 1994; Eley Associates 1997; Brohard et al. 1998), the Incentive Program for Energy Efficient Design in Utah (Case and Wingerden 1998), the New Oakland Administration Buildings (Stein et al. 2000), and six high-performance buildings reviewed by NREL (Torcellini et. 2004). In addition, on a national level, the

U.S. Green Building Council's Leadership in Energy & Environmental Design (LEED) program (USGBC 2002) was also reviewed.

The Energy Edge Program, which was sponsored by the Bonneville Power Administration (BPA) in 1986, demonstrated cost-effective energy savings in 27 new commercial buildings in the Pacific Northwest (Diamond et al. 1990, 1992). In these studies, it was found that the Energy Edge buildings consumed 30% less energy than typical new construction in the region. The authors analyzed the energy performance of the Energy Edge buildings using three types of comparisons of actual energy use: 1) to predicted energy use of design-stage simulation estimates, using the Energy Use Intensity (EUI) normalized by its conditioned floor area (kWh/ft^2-yr); 2) with energy use of similar new buildings in the region, based on end-use metering and prototype simulations; and 3) with hypothetical baseline buildings that meet the Model Conservation Standards (MCS) code requirements, which are similar to the ASHRAE Standard 90.1-1989 (ASHRAE 1989) with more stringent requirements for lighting. These comparisons are useful for the proposed research if several issues are further investigated for this study, including: baseline definitions, tuned simulation models, and energy savings analysis. In the Energy Edge project, Kaplan et al. (1992) suggested a set of general modeling issues and technical guidelines regarding significant sources of model error, simulation input, and model documentation. For this study, Kaplan's guideline will be expanded to include the use of an appropriate simulation model for the case study building, and will be enhanced by including: detailed procedures for in-situ measurements of various components such as windows, chillers, and air-handling units (AHUs).

The Advanced Customer Technology Test (ACT^2) for maximum energy efficiency program was developed from 1990 to 1997 by the Pacific Gas and Electric Company (PG&E) to determine the maximum energy savings available in a utility customer's facility using an integrated design approach (Brohard et al. 1998). The ACT^2 program was carried out at both commercial (Eley Associates 1997) and residential sites (Elberling and Bourne 1994), including: new construction and existing buildings. The ACT^2 program achieved energy savings ranging from 40-65% of the projected energy consumption of an equivalent building, which was built to California's Title 24 energy standards (CEC 1988), using an integrated package of energy efficiency measures. The authors analyzed the combined effects of individual energy efficient measures (EEMs) by adding the EEMs sequentially to the base case building (Eley Associates 1997). In this study, the ACT^2 procedure will be modified so that energy savings can be evaluated by replacing existing, efficient equipment with less-efficient equipment using simulation.

The Incentive Program of Utah was a pilot program to improve the energy efficiency of eight new state buildings in 1996 (Case and Wingerden 1998). These new buildings were designed to use 50% less energy costs than required by the ASHRAE Standard 90.1-1989 (ASHRAE 1989), without increasing their construction costs. A prototype model and a reference model were developed as baseline models using the DOE-2.1e program. The standard 90.1 prototype model predicted the energy costs of a code-compliant building with the same size and functions. A reference building was also used when the actual building's function could not be represented by a combination of the building types listed in ASHRAE 90.1-1989 (i.e., when the standard occupancy or use-profiles could not be altered to represent the proposed design, or when the owner or site requirements forced a particular form or orientation that could not be simulated.). These concepts of modeling energy baselines will be further investigated in this study, which will use Standard 90.1-2001 (ASHRAE 2001), as well as a comparison to Standard 90.1-1989 (ASHRAE 1989).

In the study of the New Oakland Administration Buildings, the project included an energy performance bonus or penalty based on the measured energy performance of the buildings in the second year of operation (Peterson and Eley 1996; Stein et al. 2000; Eley Associates 2000). The performance evaluation procedures of the new construction project included: 1) Simplified simulation methods for adjusting the target of building operation, plug loads, and other factors that were not accountable, and 2) comparing the model performance output to actual energy performance data for individual HVAC equipment. The concept of comparing the performance of an individual piece of equipment will be utilized in the study.

In 1995, the U.S. Green Building Council developed the Leadership in Energy & Environmental Design (LEED) program in response to the U.S. market's demand for a definition of "green buildings" (USGBC 2002). LEED is a rating system that evaluates the environmental performance of a facility from a whole–building perspective over a building's life cycle. To accomplish this, a set of prerequisite requirements and optional credits were identified under five categories, including: sustainable site, water efficiency, energy and atmosphere, material and resources, and indoor environmental quality. In the energy and atmosphere category of the rating system, LEED requires the user to demonstrate an energy performance level, which is referred to as the "Energy Cost Budget method" (ECB) that determines compliance with ASHRAE Standard 90.1-1999 (ASHRAE 1999). In this study, comparison with the 90.1-2001 ECB compliance paths will also be used, which is slightly more stringent than standard 90.1-1999 due to improved lighting loads.

Recently, the National Renewable Energy Laboratory (NREL) published reports on the energy performance evaluation of six high-performance buildings (Torcellini et al. 2004). In this evaluation, they performed post-occupancy evaluation and sub-system analysis with extensive energy monitoring. They then used an as-built simulation or measured data or utility bills to calculate energy savings compared to a code-compliant baseline model. For example, site energy savings were calculated by comparing baseline code models with direct measurements (Zion and CBF) or as-built simulation models (Oberlin, TTF, and BigHorn) with TMY2 weather. Energy cost savings were calculated by comparing baseline code models with utility bills (Oberlin and Zion) or as-built model (Oberlin, TTF, and BigHorn). Appendix A includes descriptions of the NREL study in terms of monitoring, base case model, as-built simulation, and sub-system analysis. Unfortunately, the studies didn't provide detailed descriptions of how the authors developed code baselines and as-built model calibrations. Table 2.1 summarizes the energy performance evaluations of the six high-performance buildings performed by NREL.

Table 2.1 Summary of the Energy Performance Evaluation of Six High-Performance Buildings

Building Name	Simulation Program	As-built Model	Baseline Model Standard 90.1 Version	Energy savings (%)	
				Site Energy	Energy Cost
Oberlin	DOE-2.1E	Yes	2001	47%	35%
Zion	DOE-2.1E	No	1999	62%	67%
TTF	DOE-2.1E	Yes	1995 FEC based on ASHRAE 1989	42%	25%
CBF	EnergyPlus	No	2001	51%	12%
BigHorn	DOE-2.1E	Yes	2001	35%	53%
Cambria	Report not published			40%	43%

In summary, the new construction program evaluations reviewed above provide various Measurement and Verification (M&V) methods for modeling energy baselines and estimating energy savings. Unfortunately, there is a lack of standard M&V methods to measure energy savings from new buildings. Selected M&V methods from the previous studies will be combined into the analysis for this study in the hopes of developing a standard, reproducible M&V methodology that could be applied to other similar buildings, including: how to create the simulation model with Energy Conservation Design Measures (ECDMs), how to develop energy baselines, and how to calculate energy savings from ECDMs in a new commercial building.

2.2 Energy Measurement and Verification (M&V) Methods

The International Performance Measurement & Verification Protocol (IPMVP 2001), ASHRAE Guideline 14 (ASHRAE 2002), and Federal Energy Management program (Schiller Associates 2000) are the primary U.S. protocols that have developed M&V methods to calculate energy savings from building retrofits and selected M&V approaches for new buildings.

The IPMVP was first published in 1996 as the North American Energy Measurement and Verification Protocol (NEMVP 1996), with revisions released in 1997, 2001, and 2003. The protocol provides an overview of current best practice techniques available for verifying energy and water savings, as well as M&V for indoor environmental quality. The current IPMVP has been divided into three separate volumes. Volume I defines general M&V concepts and options for building retrofits (IPMVP 2001). Volume II reviews indoor environmental quality (IEQ) issues that may be influenced by an energy efficiency project (IPMVP 2001). Volume III has recently been published for new construction, which provides a basic M&V framework in accordance with M&V options A, B, C, and D (IPMVP 2003). Table 2.2 shows an overview of M&V options described in the IPMVP Volume III-new construction (IPMVP 2003). Option A and B focus on the performance of specific and easily isolated ECMs. Option A is suitable for ECMs with constant and predictable loads such as lighting equipment, while Option B is suitable for ECMs with variable loads such as variable speed fan and pump. Option C provides a method for estimating whole-building energy performance compared to other similar buildings in a control group. Option C is suitable only for projects where existing buildings are available for comparison, which are physically and operationally similar buildings without the ECMs. Finally, Option D uses calibrated simulation to determine energy savings at the whole-building or system level. In this research, the generic M&V framework in the IPMVP (IPMVP 2003) will be modified and enhanced with detailed M&V procedures applicable to energy efficient new buildings, including: in-situ measurements of whole-building and energy efficient components such as high efficiency centrifugal chillers, variable-speed dual-duct Air Handling Units (AHUs), and low-e glazing.

Table 2.2 Summary of New Construction M&V Options in the IPMVP (IPMVP 2003)

M&V Option	Description	Baseline Energy Use Projected	Typical Application
Option A	**Partially Measured Retrofit Isolation.** Savings are determined by partial measurement	By calculating the hypothetical energy performance of the baseline system under post-construction operating conditions	ECMs with constant loads, such as lighting systems
Option B	**Retrofit Isolation**. Savings are determined by full measurement of energy use and operating parameters of the ECMs		ECMs with variable loads, such as variable speed fan and pump drives, chillers, boilers, etc.
Option C	**Whole Facility.** Savings are determined at the whole-building level by measuring energy use at main meters or with aggregated sub-meters	By measuring the whole-building energy use of similar buildings without the ECMs	New building with energy efficient features
Option D	**Calibrated Simulation**. Savings are determined at the whole-building or system level using whole-building simulation calibrated to measured energy use data	By energy simulation of the baseline under operating conditions of the M&V period	A new building performance contract, with local energy code defining the baseline

ASHRAE Guideline 14-2002 contains energy and demand savings calculation procedures for building energy retrofit projects (ASHRAE 2002). The guideline includes three approaches for determining energy and demand savings, including: a whole-building approach that involves the use of monthly utility billing data or data gathered from a main meter, a retrofit isolation approach that uses metered systems as a basis for determining savings, and a whole-building calibrated simulation approach that is used to predict energy use of the post-retrofit conditions. Although this guideline was originally developed for existing building retrofits, the proposed M&V concepts and approaches can be applied to determine energy savings for new buildings if pre-retrofit energy use is conceptually replaced with the simulated energy baseline of a new building. The guideline also provides instrumentation and data management, including: physical measurements and uncertainty analysis. This guideline will be useful for the energy measurement and data analysis of the case study building.

The Federal Energy Management Program (FEMP) Guideline was first published in 1996 to reduce energy costs to the U.S. Government from operating federal facilities. Revisions were released in 1998 and 2000 (Schiller Associates 2000). The FEMP Guideline provides guidelines and methods for measuring and verifying the savings implemented with federal Energy Savings Performance Contracts (ESPCs) and the SuperESPC Program. The 2000 FEMP Guideline, which claims compatibility with the IPMVP, contains a chapter for new construction projects, including: an overview of new construction M&V options, which are similar in concept to the retrofit M&V options that were proposed in the IPMVP. The M&V options of the IPMVP and the FEMP Guideline will therefore be considered to evaluate energy savings for the case study building.

In summary, the M&V guidelines reviewed above can be classified as general M&V protocols (IPMVP), technical guidelines with procedures (ASHRAE Guideline 14), and specific application of the IPMVP to federal energy management projects (i.e., the FEMP Guideline). In this study, the general M&V concept will follow the IPMVP and the ASHRAE Guideline 14-2002, with detailed M&V procedures, including: in-situ measurements of the selected components such as windows, chillers, and AHUs of the case study building. ASHRAE Guideline 14-2002 will also be investigated in detail in terms of instrumentation and data management, as well as performance evaluation approaches.

2.3 Baselines for Building Energy Use

Energy use baselines play a critical role in measuring energy savings for new buildings, as well as energy retrofits in existing buildings. Existing methods for developing energy baselines were reviewed, and three representative energy standards were also reviewed as one of code-compliant baselines for new buildings.

2.3.1 Energy Use Baselines

Several studies were reviewed for developing energy baselines (MacDonald and Wasserman 1989; Akbari et al. 1990; Reddy et al. 1997; Turner et al. 1998; Haberl et al. 1998; Kissock et al. 2001). MacDonald and Wasserman (1989) investigated existing methods used for analyzing metered energy data, including: five general categories: (1) annual total energy and energy use intensities (EUIs) (2) linear regression and component models, (3) multiple linear regression models, (4) building simulation programs, and (5) dynamic thermal performance models. In this study, annual total energy and energy use intensities (EUIs) can be used for quick comparisons of the case study building to other reference buildings. Akbari et al. (1990) also reviewed and compared existing studies of energy use intensities (EUIs) and load shapes in the commercial sector. The EUIs were compared to electric end use data for lighting, miscellaneous, refrigeration, and cooling energy according to building types. Such a comparison will be useful in this study to compare with the energy characteristics of the case study building.

Two types of analytical approaches were suggested in the Texas LoanSTAR program (Turner et al. 1998; Haberl et al. 1998) to develop energy baselines, including: calibrated engineering models and regression models (or inverse models). In most cases, calibrated simulation models have been used when pre-retrofit energy use was limited, while the baseline statistical models have been used to predict the baseline use in the post-retrofit period. Baseline energy use should be normalized for certain changes, such as weather, conditioned area, occupancy levels, and connected loads (Reddy et al. 1997). The use of weather-normalized models has been one of the noteworthy features of developing energy baseline models. Kissock et al. (2001) developed the Inverse Modeling Toolkit (IMT), sponsored by ASHRAE research project 1050-RP, for calculating the regression models for a baseline. IMT can find best-fit models according to the number of change points. Appropriate change-point linear regression models will be useful to develop energy baselines for selected components of the case study building.

In summary, annual total energy and energy use intensities (EUIs) can be used for quick comparisons of the case study building to other reference buildings. Calibrated simulation will be used as the primary tool in this study to develop energy baselines. Regression models will also be used as a secondary tool to identify relationships between factors that influence building energy use or for analyzing a certain component.

2.3.2 Energy Standards and Codes

Energy standards and codes have played a critical role in setting the design goals and developing energy baselines for new buildings. Three representative energy standards were reviewed as one of code-compliant baselines for new buildings, including: ASHRAE Standard 90.1-2001 (ASHRAE 2001) as a federal standard, the 2000 International Energy Conservation Code (ICC 2000) as an international standard, and California's Energy Efficient Standards for Residential and Nonresidential Buildings (Title 24) as a state standard (CEC 2001).

ASHRAE Standard 90.1, which provides the minimum requirements for the design of energy-efficient buildings except low-rise residential buildings, was first released in 1975 and revised in 1980, 1989, 1999, 2001, and 2004. Standard 90.1 is scheduled to be updated every three years in the future, with addendums published in-between the new versions. ASHRAE 90.1-1999 contains numerous improvements over the 1989 version, along with enhanced energy efficiency levels. ASHRAE 90.1-2001 includes the entire 1999 version along with 34 new addenda. The 90.1 Standard offers an alternative whole-building approach, the "Energy Cost Budget" (ECB) method, to allow for compliance with the standard in addition to mandatory requirements for building components, including: the building envelope, lighting systems, HVAC systems, and other equipment. ASHRAE 90.1-2004 provides an informative Performance Rating Method (PRM) that is a modification of the ECB method. The PRM is intended to quantify performance that substantially exceeds the requirements of the 90.1 Standard. In this study, the ASHRAE Standard 90.1-2001 ECB compliance methods will be investigated, along with selected mandatory and prescriptive requirements that are required for code compliance.

The International Energy Conservation Code (IECC), first issued in 1998, replaced the 1995 edition of Model Energy Code (MEC) (ICC 2000). The International Code Council (ICC) has the responsibility for maintaining the IECC. The ICC also plans to update the 2000 IECC in three-year intervals. The 2000 IECC contains prescriptive and performance-based methods for both residential and commercial buildings. In Chapter 8 of the IECC, minimum efficiency requirements are provided for the building envelope, mechanical systems, service water heating, and lighting systems. General guidelines are also provided in determining total building performance. The 2000 IECC with the 2001 supplement is the Texas State energy code, which refers to ASHRAE Standard 90.1-1999 in Chapter 7 of the IECC as an alternative method. Therefore, the 2000 IECC requirements for commercial buildings will not be investigated in this study.

California’s Energy Efficient Standard for Residential and Nonresidential Buildings (Title 24) (CEC 2001) was established in 1978 in response to a state legislative mandate to reduce California's energy consumption. The standards are updated periodically to allow for consideration and possible incorporation of new energy efficiency technologies and construction methods. Title 24 also includes performance and prescriptive compliance approaches for achieving energy efficiency, as well as mandatory requirements, which are not directly applicable to this study since it was specially developed for the climate zones of California. However, Title 24’s compliance approach is useful as a reference standard when compared to the ECB method of ASHRAE 90.1-2001.

In relation to the building energy standards and codes, simplified computer programs have been developed to demonstrate compliance with energy codes (e.g., ASHRAE Standard 90.1-1989; 2000 IECC) for commercial and high-rise residential building design, such as COMcheck-EZ (DOE 2000) and COMcheck-Plus (DOE 2001). Although these simple programs enable a rapid assessment of a building’s energy performance with minimal data input, this approach limits the types and complexity of buildings that can be modeled. Therefore, a calibrated simulation of the case study building will be used in this study for the performance evaluation of the new building.

In summary, the energy standards reviewed above provide performance and prescriptive compliance approaches, as well as mandatory requirements for energy efficient buildings. In this study, the calibrated simulation for the case study building will be compared against ASHRAE 90.1-1989 and ASHRAE 90.1-2001 to determine how efficient the case study building is compared to these standards.

2.4 Building Energy Simulation and Calibration

2.4.1 Building Energy Simulation Programs

A wide variety of energy simulation programs are currently available from many organizations, utilities, and private consultants. Building energy simulation programs have become fundamental design tools, which are used to quantify the annual energy use of proposed energy conservation measures in new and existing buildings. Public energy analysis programs in the U.S. are represented by three main code development efforts (Ayres 1995), including: DOE-2 (LBNL 1981), BLAST (BSO 1993), and EnergyPlus (DOE 2001).

The DOE-2 program is a public-domain computer program for building energy analysis, which has been developed and maintained by the Lawrence Berkeley National Laboratory (LBNL 1981). The DOE-2 program predicts the energy use and energy costs of a building based on hourly weather information, a description of the building, and its HVAC equipment. Since DOE-2 allows a user to decide how precisely to model a specific building, the amount of detail required for simulation depends upon how detailed and how accurate the user wants the results to be. The DOE-2 program has a capability to model the thermal and, to a limited extent, the daylight behavior of windows in detail when used in conjunction with the Window 5 program, which adopts the NFRC (National Fenestration Rating Council) procedures for calculating the thermal performance of windows (Reilly et al. 1995). Although the DOE-2 program supports daylighting better than most other hourly simulations, it has some limitations regarding the daylighting calculations for specific configurations, such as light shelves (Baker 1990; LBNL 1993). In terms of capabilities and reliability, the DOE-2.1e program is considered an accurate energy simulation program in this study.

The Building Loads Analysis and System Thermodynamics (BLAST) program is a set of programs for predicting heating and cooling energy consumption in buildings and analyzing energy costs using the Heat Balance Loads Calculator (HBLC) (BSO 1993). BLAST can also be used to investigate the energy performance of new or retrofit building design because the heat balance method has long been recognized as a fundamentally sound approach to heating and cooling load calculations. The BLAST program has limitations on daylighting and illumination calculations and controls (Crawley et al. 2000). One additional limitation to the BLAST program is that the user can't modify the program code without recompiling it. Therefore, the BLAST program may not be suitable for simulating the case study building, which contains specially designed daylight features with daylight dimming systems, and will not be used in this study.

EnergyPlus (DOE 2001) is a new building performance simulation program with features from BLAST and DOE-2, along with new capabilities, including integrated simulation and a multiple time step approach simulation (Crawley 2000). By using an integrated solution technique, EnergyPlus can predict more accurate space temperatures for evaluation of system and plant size, and occupant comfort.

EnergyPlus is being updated with increasing capabilities by linking it to other programs, such as the COMIS (Conjunction Of Multizone Infiltration Specialists) airflow program (LBNL 1989) and other special purpose programs. In the future, EnergyPlus is intended to replace the DOE-2 and BLAST programs. However, currently its use is limited to the consulting firms and universities that created the program because of its complexity. Therefore, it will not be used in this study.

In conclusion, the energy performance of a new building can be evaluated with one of several public domain building simulation programs that offer a wide capability for simulating design features. In this study, the DOE-2 program, along with the Window 5.1 program, will be used to simulate the case study building.

2.4.2 Simulation and Calibration Methods

Many building energy studies and ASHRAE research projects have been reporting on efforts to calibrate simulations to measured data from monthly utility data (Diamond and Hum 1981; McLain et al., 1994), to hourly measured data (Hsieh 1988; Hinchey 1991; Kaplan et al. 1990, 1992; Bronson et al. 1992; Huang 1994; Haberl et al. 1995; Huang and Crawley 1996; Haberl and Bou-Saada 1998; Abushakra 2001; Reddy 2004). Furthermore, in-situ measurements of HVAC&R equipment (Phelan et al. 1997; Haberl et al. 1997; Liu et al. 2002) have been performed to support the effectiveness of calibrated simulation. Such calibration methods are useful in this study to improve the accuracy and reliability of a new building simulation, including: equipment performance, day-type profiles, weather data, and daylighting systems.

Some of the first published calibration procedures were developed in the two office buildings reported by Hsieh (1988), including: calibration of tenant energy use, HVAC equipment operation schedules and thermostat set points, heating and cooling equipment performance, building shell heat loss coefficient, zone definition in DOE-2, outside air intake, and weather data. Of these factors, the calibration technique for equipment performance is one of the main factors to be used in this study because the DOE-2 program only provides standard default performance values that may not be related to the high efficiency equipment installed in the case study building.

Kaplan et al. (1990) developed “day-typed schedules” to incorporate monitored lighting and equipment data into the typical operating schedule in the DOE-2 model. Such day-typed schedules showed that monitored data could be used to generate simulation inputs, as well as to verify simulation outputs for calibrating the simulation model. Abushakra et al. (2001) performed the ASHRAE research project 1093-RP for developing procedures to derive the diversity factors and typical load shapes of lighting and receptacle loads in office buildings. They used percentile analysis to derive load shapes and diversity factors. In this study, the 50% percentile was used to represent the typical weekday and weekend day-type load profiles of the case study building.

Haberl et al. (1995) evaluated the impact of using measured weather data that was repacked into Test Reference Year (TRY) format vs. TMY format in a DOE-2 simulation by comparing the results of simulated energy use. The authors found that the use of packed weather files significantly improved the cooling energy simulation for their case study building. Huang and Crawley (1996) also compared the influence of the various weather data sets, including: TRY, TMY, TMY2, WYEC (Weather Year for Energy Calculations), and WYEC2, on simulated annual energy use and energy cost. Huang and Crawley (1996) recommended that TMY2 (Marion and Urban 1995) should be used in building energy simulations where solar radiation is critical to the results. Therefore, in this study, packed TRY weather files with solar data will be used to calibrate the simulation model of the case-study building, but annual simulation with TMY2 weather data will also be used to calculate the annual average values.

Daylighting has also been considered as one of the promising design strategies for new buildings in terms of energy savings (McHugh et al. 1998). Papamichael and Beltran (1993) suggested a new method called the IDC (Integration of Directional Coefficients) method, which is based on the combination of scale model photometry and computer-based simulation, for the daylight performance of fenestration systems that incorporate specific daylight components, such as venetian blinds, light shelves, and light pipes. Lee et al. (1994) studied integrated envelope and lighting systems, which achieved significant peak demand reductions and energy savings for new commercial buildings. In other studies, the impact of daylight utilization has been determined using an energy simulation program such as DOE-2 (LBNL 2002) for heating and cooling loads, energy use, and peak electrical demand (Winkelmann and Selkowitz 1985). Rungchareonrat (2003) also evaluated the lighting electricity and cooling energy savings potential from the use of different shading devices applied to residential fenestration using DOE-2 proxy models in combination with a physical scale model and site measurements (e.g., daylight factors). Therefore, this study will investigate the use of DOE-2's daylighting simulation for the daylighting systems with low-e windows in the case study building using the proxy models.

An effective calibrated simulation often requires in-situ performance measurement of the mechanical equipment, especially for high efficient equipment that is used for new high performance buildings. Phelan et al. (1997) developed a set of in-situ testing methods of pumps, fans, and chillers under ASHRAE Research Project RP-827 to evaluate annual energy consumption and to account for part-load operations that are affected by overall system controls. In order to characterize chiller performance, they used two versions of a thermodynamic model depending on evaporator and condenser temperature changes during operation, including the simple chiller model and the temperature-dependent chiller model. They developed appropriate chiller models using statistical regression analysis based on one year hourly measured data, including: chiller power consumption, evaporator flow rates, and chilled water and condenser water supply and return temperature. In this study, a chiller performance will also be measured to develop an appropriate chiller performance curve if it is significantly different from the DOE-2 default curve when compared to each other. Other equipment performance such as pumps and fans will follow the DOE-2 default curves due to lack of sub-metered data from the case study building.

Liu et al. (2002) has been developing a procedure to determine the in-situ performance of commonly used HVAC systems sponsored by ASHRAE Research Project RP-1092. The research objectives are to develop a simplified model calibration procedure from short-term field measurement and validate the calibration procedure using a simulation program developed with the ASHRAE modified bin method. In this study, short-term field measurements for a typical AHU of the case study building will also be performed to verify actual system operation as a part of detailed DOE-2 model calibration.

Recently, ASHRAE Research project RP-1051 (Reddy 2004) has developed sophisticated procedures for reconciling computer-calculated results with measured energy data. The purpose of this RP-1051 project is to develop a coherent and systematic calibration methodology and well-documented toolkit of the calibration procedure. As a part of the project RP-1051, broad ranges of literature were reviewed in detail on calibration of building energy simulation programs related to uses, problems, procedures, uncertainty, and tools (Reddy 2006). Similarly, a systematic calibration methodology will be developed with parameter estimation and also demonstrated in this study using a case study building, which is a new building with several energy efficient features.

In summary, many of the simulation and calibration methods in the literature have been shown to be useful for new buildings with ECDMs. Selected methods from the previous studies will be modified and used with on-site measurements to develop a calibrated simulation of the case study building.

2.4.3 Graphical and Statistical Calibration Techniques

Graphical and statistical calibration techniques have been reviewed from the previous literature (Hinchey 1991; Bronson et al. 1992; Huang 1994; Kreider and Haberl 1994; Soebarto 1996; Haberl and Bou-Saada 1998; Wei et al. 1998).

Graphical comparisons can be used to effectively represent the difference between simulated and measured data in the process of calibration. Most graphic comparisons are generally represented using bar charts, monthly percent difference time series graphs, and x-y scatter plots. Advanced graphical techniques have been demonstrated with building energy data, such as comparative 3-D time-series plots (Hinchey 1991) and nine-graph carpet plots (Bronson et al. 1992), which allow for very small differences in simulated versus measured dry-bulb temperature and specific humidity to be readily viewed. Architectural rendering of the input files is now possible; for example, Huang (1994) developed the DrawBDL to read and display a DOE-2 BDL input file. These graphical methods have been shown to effectively represent the simulated results and measured data from the case study building.

Soebarto (1996) developed a user-interface program to represent the calibration results with several graphical outputs such as total disaggregated energy use, 24-hour profiles for the workday and weekends, and hourly energy end uses with residuals. Haberl and Bou-Saada (1998) developed hourly comparison techniques, including: a temperature bin analysis to improve hourly x-y scatter plots, a 24-hour weather-daytype bin analysis to allow for the accurate evaluation of hourly temperature and schedule- dependent comparisons, and a 52-week bin analysis to facilitate the combined graphical and statistical evaluation of long-term trends. Wei et al. (1998) developed a unique graphical representation referred to as “calibration signatures” of different parameters on the heating and cooling energy consumption of typical air handling units (AHUs) for model calibration. These graphical techniques will be useful in the proposed work during the process of simulation and calibration.

Several statistical methods have also been developed to access the goodness-of-fit of a simulation model, including: percent difference, mean bias error (MBE), and use of the coefficient of variation of the root mean square error (CV(RMSE)) (Kreider and Haberl 1994). The percent difference is a simple calculation to identify the difference between measured and simulated energy data. The mean bias error (MBE) is a method to determine a non–dimensional bias measure between the simulated data and the measured data for each individual hour. The coefficient of variation of the root mean square error (CV(RMSE)) is essentially the root mean square error divided by the measured mean of all the data. These statistical methods will be used in this study to determine how well the simulation model fits the data in the process of calibration (i.e., the lower the CV(RMSE), the better the calibration) (Haberl and Bou-Saada 1998).

In summary, a number of graphical and statistical calibration techniques have been reviewed using a selection of these methods that show promise for use in the proposed study. The case study building will be calibrated until the simulation results match with measured data to a suitable level as evaluated with hourly MBE, RMSE, and CV(RMSE). Various graphical techniques selected from the procedures that were reviewed will also be used to adjust calibration parameters and to evaluate the calibration results.

2.5 Summary of Literature Review

This literature review provided an overview of (1) energy efficient programs; (2) measurement and verification (M&V) programs; (3) energy baseline development; and (4) energy simulation programs and calibration methods. Several new construction programs were reviewed in terms of energy performance evaluation, as well as their effectiveness to improve energy efficiency. For the performance evaluation of new buildings, M&V programs were also reviewed, which include general M&V protocols (IPMVP), technical guidelines with procedures (ASHRAE Guideline 14), and the application of the IPMVP to the Federal Energy Management Project (FEMP). The IPMVP published Volume III, which provides a basic M&V framework for new construction in accordance with M&V options A, B, C, and D

(IPMVP 2003). Unfortunately, these programs provided only limited M&V methods for new buildings. Therefore, the generic M&V framework will be enhanced with detailed M&V procedures, including: in-situ measurements of the selected components such as windows, chillers, and AHUs, and will be applied to a case-study building. Building energy baselines were reviewed to determine relative energy savings in terms of metered energy use data analysis and baseline calculation approaches. Three representative energy standards were reviewed as energy baselines for energy efficient buildings. In this study, ASHRAE 90.1-1989 will be compared against ASHRAE 90.1-2001 in terms of energy performance improvement when applied to the calibrated simulation for the case study building. In this study, energy use baselines will also be used, including: codes such as ASHRAE Standard 90.1-2001, design conditions without ECMs (component isolation), and reference buildings. Among the public domain energy simulation programs, the DOE-2 program, along with the Window 5.2 program (LBNL 2001), are considered the most widely used simulation tools. These programs are also accurate programs, yet are flexible enough to allow for the application to complex buildings such as the case-study building used in this study. Finally, various simulation and calibration methods were reviewed for new buildings, regarding equipment performance, operating schedules, on-site weather data, daylighting systems, and graphical and statistical techniques. These methods will be applied for the calibration of the case study building to a certain level because the calibration factors and procedures have been shown to be useful for new buildings that could include ECDMs.

CHAPTER III

SIGNIFICANCE OF THE STUDY

3.1 Significance of the Study

This study developed and demonstrated new methodologies for evaluating the energy performance of new commercial buildings using a case-study building in Austin, Texas, including: 1) Three new Measurement and Verification (M&V) methods, 2) Three new simulation and calibration methods applicable to new buildings, 3) A new analysis of actual energy savings compared to three different energy baselines, and 4) A new evaluation of potential energy savings simulated from selected improvements. This research will contribute to enhance the generic M&V framework (IPMVP 2003) for new buildings and promote new construction programs based on energy-efficient designs.

3.2 Scope and Limitation of the Research

This research was limited to evaluations of whole-building energy performance for a case-study building with selected ECDMs that were simulated using the DOE-2.1e program, including: a high efficiency boiler, chiller, an oversized cooling tower, low head pumps, VFD fans, dual-duct VAV systems, and low-e glazing. Unfortunately, some of the ECDMs installed in the REJ building could not be simulated in this study due to limitations with the DOE-2.1e program and sub-metered data, including: enthalpy-based heat recovery on the senate print shop, dual-duct dual fan systems, and run-around glycol coil. These measures need a more sophisticated simulation program and sub-metered data for the certain component.

CHAPTER IV
METHODOLOGY

This chapter describes the methodology and the case study building used in this research. This methodology chapter contains six Sections, including: (1) Case study building description, (2) Energy Measurement and Verification (M&V), (3) Baselines for building energy use, (4) Energy metering and in-situ measurements, (5) As-built simulation and calibration, and (6) Summary of the methodology.

4.1 Case Study Building Description

The Robert E. Johnson (REJ) state office building in Austin, Texas was designed by the Page, Southerland Page architects (PSP) to be a sustainable design project funded by the Texas State Energy Conservation Office (SECO). Figure 4.1 shows the site map of the REJ building. Overall, the building is divided into three Sections with divisions created by a ground-level breezeway and vehicular access area. Upper floors extend above these areas. This Section describes the REJ building based on the information from as-built drawings, site visits, and the previous report (Sylvester et al. 2002), including: building, Heating Ventilating and Air Conditioning systems (HVAC) systems, and Energy Management Control Systems (EMCS).

4.1.1 Building Description

The Robert E. Johnson (REJ) state office building is a six-story, 303,389 square foot office building for state legislative support staff, such as House Committees, the Legislative Council, the State Auditor, the Legislative Reference Library, and the Senate Print Shop. The REJ building contains over 50% of the windows in the façade consisting of two types of glazing. Deciduous trees shade a significant portion of the south façade up to approximately the 3rd floor as shown in Figure 4.2. The building's south façade with a vehicular access area and the north façade with building shading are shown in Figure 4.3 and Figure 4.4, respectively. Specially designed light shelves with dimmable ballasts, shown in Figure 4.5, were partially installed on the south façade (3rd through 5th floors) of the building to project the daylight into the interior office. However, on-site inspections (Sylvester et al. 2002) revealed that most window blinds, shown in Figure 4.6, were closed on all glazed surfaces, negating the effect of the daylighting-dimming equipment.

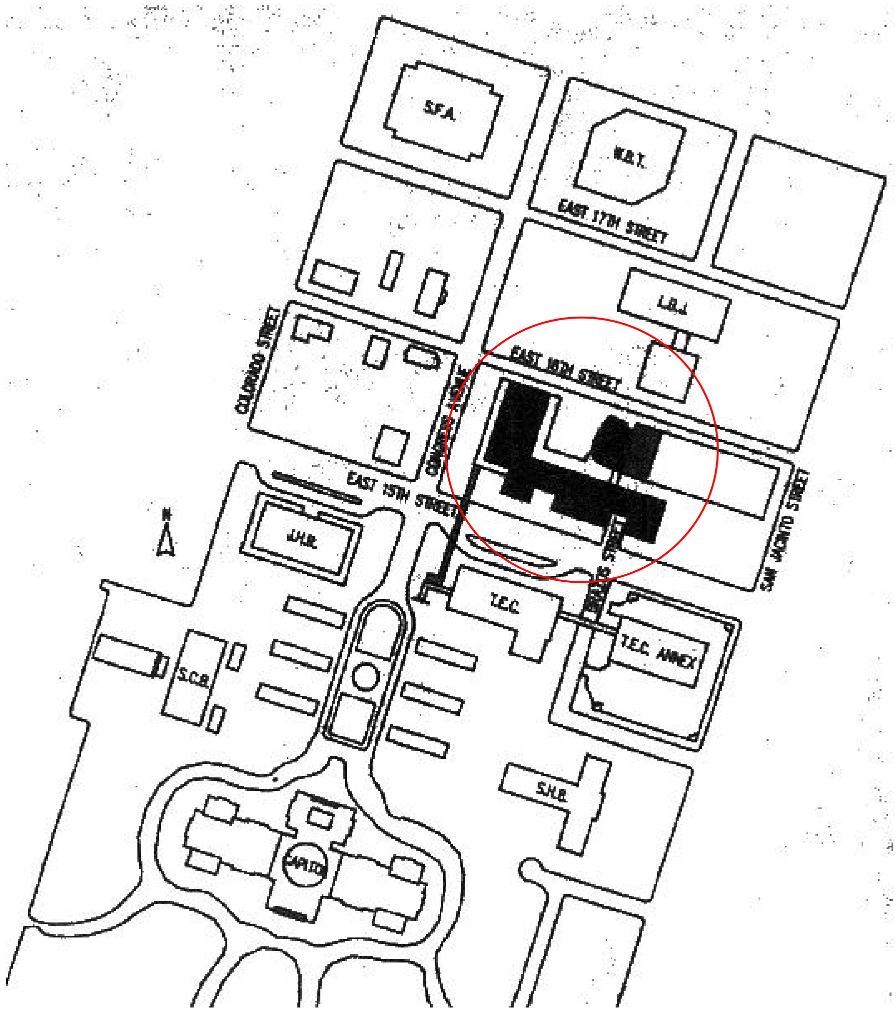


Figure 4.1 *Site map of the Robert E. Johnson (REJ) state office building in Austin, Texas.*
(Source: As-built architectural drawing for the REJ building).

Figure 4.2 *The building's south façade with deciduous trees in summer.*

Figure 4.3 *The building's south façade with vehicular access area.*

Figure 4.4 *The building's north façade with building shadings.*

Figure 4.5 *Typical southern view of open office plan with light shelves.*

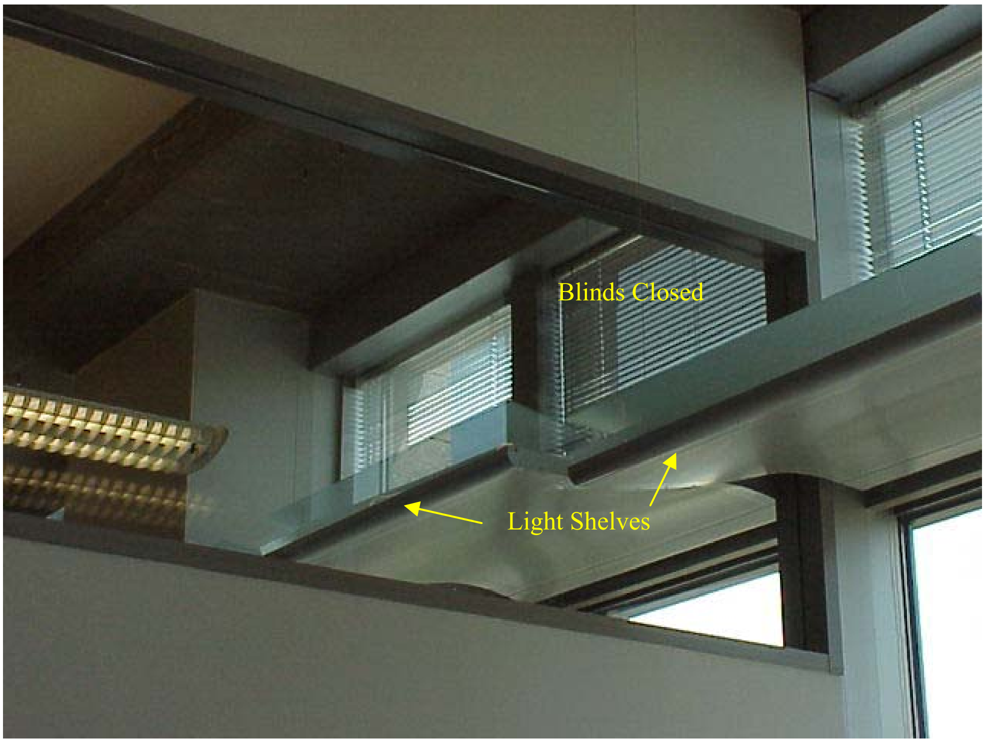


Figure 4.6 *Light shelves with the blinds closed in the clearstory window.*

4.1.2 HVAC Systems

The majority of the conditioned area in the REJ building is served by the Dual-duct, Variable Air Volume (DDVAV) systems, as shown in Figure 4.7, with preconditioned outside air flowing through the run-around glycol coil (before and after the preconditioning coil), as shown in Figure 4.8. Two Outside Air (OA) units on the roof of the REJ building provide the east and west Air Handling Unit (AHU) in each floor with pre-conditioned OA, which is controlled by CO2 space sensors located in the respective zones.

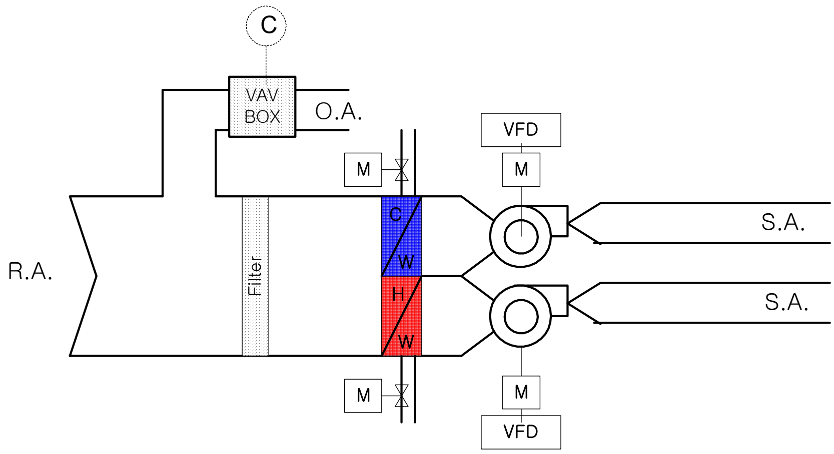


Figure 4.7 *Dual-duct Variable Air Volume System (DDVAV).*

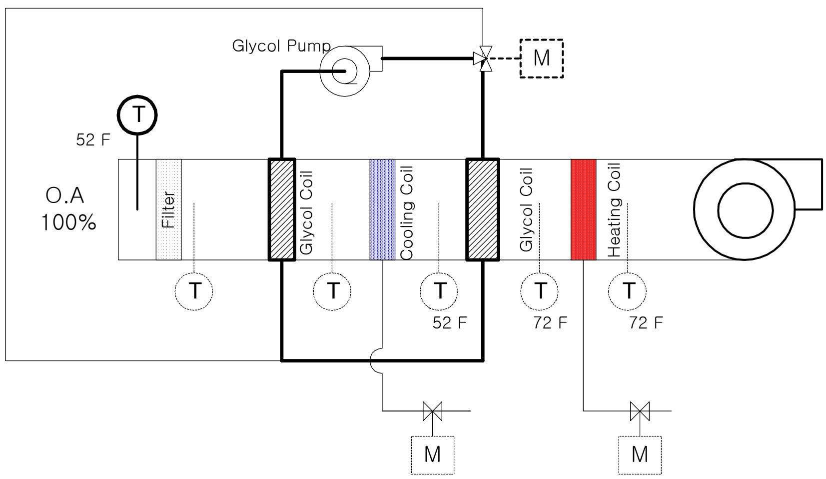


Figure 4.8 *Outside Air unit (OA-1 and OA-2) with a run-around coil.*

Table 4.1 specifies the design conditions for the DDVAV units in each service area, which is obtained from the REJ as-built drawing. Fan efficiency for each AHU was calculated from design supply cfm (ft^3 /min), pressure (inWG), and horse power (hp), using the following equation (Kreider and Rabi 1994):

$$Fan(\eta) = \frac{V(ft^3/\min) * H(inWG)}{6356 * hp} \tag{4.1}$$

Table 4.1 Typical AHU (DDVAV) Systems of the REJ Building

Types	AHUs	Serves	Supply CFM	Pressure (In. wg)	HP	kW	Fan Efficiency	Remarks
OA Unit	OA-1	WEST AHU'S	20,800	3.70	15.0	20	0.8	West OA Roof Top Unit with Glycol Piping
	OA-2	EAST AHU'S	20,800	3.70	15.0	20	0.8	East OA Roof Top Unit with Glycol Piping
DDVAV (Cooling)	CC-1E	1st Floor East	26,200	2.50	20.0	27	0.5	* Dual Duct (Duel Fan) Variable Air Volume (VAV) system * OA is controled by CO2 space sensor located in the respective zone
	CC-1W	1st Floor West	19,350	2.50	15.0	20	0.5	
	CC-2E	2nd Floor East	26,200	2.50	20.0	27	0.5	
	CC-2W	2nd Floor West	25,700	2.50	20.0	27	0.5	
	CC-3E	3rd Floor East	26,200	2.50	20.0	27	0.5	
	CC-3W	3rd Floor West	25,700	2.50	20.0	27	0.5	
	CC-4E	4th Floor East	26,300	2.50	20.0	27	0.5	
	CC-4W	4th Floor West	25,900	2.50	20.0	27	0.5	
	CC-5E	5th Floor East	29,600	2.50	20.0	27	0.6	
	CC-5W	5th Floor West	27,700	2.50	20.0	27	0.5	
	CC-6W	6th Floor West	19,350	2.50	15.0	20	0.5	
DDVAV (Heating)	HC-1E	1st Floor East	13,100	2.50	10.0	13	0.5	* Dual Duct (Duel Fan) Variable Air Volume (VAV) system * OA is controled by CO2 space sensor located in the respective zone
	HC-1W	1st Floor West	9,700	2.50	10.0	13	0.4	
	HC-2E	2nd Floor East	13,100	2.50	10.0	13	0.5	
	HC-2W	2nd Floor West	12,850	2.50	10.0	13	0.5	
	HC-3E	3rd Floor East	13,100	2.50	10.0	13	0.5	
	HC-3W	3rd Floor West	12,850	2.50	10.0	13	0.5	
	HC-4E	4th Floor East	13,150	2.50	10.0	13	0.5	
	HC-4W	4th Floor West	12,950	2.50	10.0	13	0.5	
	HC-5E	5th Floor East	14,800	2.50	10.0	13	0.6	
	HC-5W	5th Floor West	13,850	2.50	10.0	13	0.5	
	HC-6W	6th Floor West	9,700	2.50	10.0	13	0.4	

(Source: As-built mechanical drawing for the REJ building).

For the basement air conditioning, four types of AHU systems are installed according to each space condition, including: bypass multi-zones as shown in Figure 4.9, single-duct Variable Air Volume (VAV) without heating coil, single duct Constant Air Volume (CAV) AHU systems with humidifiers as shown in Figure 4.10 and with a heat wheel unit as shown in Figure 4.11, and Computer Room Units (CRUs). Table 4.2 specifies design conditions of each unit in each service area of the REJ building, including: supply CFM, static pressure, horse power (hp), and fan efficiency.

Table 4.2 Basement and Conference Center AHU Systems of the REJ Building

Types	AHUs	Serves	Supply CFM	Pressure (In. wg)	HP	KW	Fan Efficiency	Remarks
OA-Unit	OA-3	Conference Room	3,854	3.00	10.0	13	0.2	Heat recovery system
By-Pass Multizone	AHU-C-1	Conference Room	12,275	3.00	10.0	13	0.6	Heat recovery system
	AHU-P-1	DPS Area	4,100	2.25	5.0	7	0.3	1st Floor
	AHU-B-1	IS/NS-H	5,100	2.13	5.0	7	0.3	Basement
Single Duct VAV	AHU-B-3	Senate Print Admin.	4,650	2.43	5.0	7	0.4	No heating coil, Basement
	AHU-B-4	Lower Lvl. Serve. Area	4,150	2.49	5.0	7	0.3	No heating coil, Basement
	AHU-B-5	Dock / Electrical	4,650	2.43	5.0	7	0.4	No heating coil, Basement
	AHU-B-6	DP Admin	6,000	2.74	7.5	10	0.3	No heating coil, Basement
Single Duct CAV	AHU-B-2	Senate Print	16,500	2.41	15.0	20	0.4	Humidifier(electric steam), Basement
	AHU-B-7	DP print	15,600	2.31	15.0	20	0.4	Humidifier(electric steam), Basement Heat Wheel Unit
	AHU-B-8	Tunnel (Pedestrian)	1,950	1.50	1.0	1	0.5	No heating coil
Computer Room Unit(CRU)	CRU-1	Computer room	8,700	0.30	7.5	10	0.1	LIEBERT MODEL # FH 376C
	CRU-2	Computer room	8,700	0.30	7.5	10	0.1	
	CRU-3	Computer room	8,700	0.30	7.5	10	0.1	
	CRU-4	Computer room	8,700	0.30	7.5	10	0.1	
	CRU-5	Computer room	8,700	0.30	7.5	10	0.1	
	CRU-6	Computer room	5,675	0.30	5.0	7	0.1	LIEBERT MODEL # FH 248C
	CRU-7	Computer room	5,675	0.30	5.0	7	0.1	

(Source: As-built mechanical drawing for the REJ building).

The REJ building contains high efficient mechanical equipment, including: two low-NOx boilers, three high efficiency centrifugal chillers, and two oversized cooling towers with 20 horsepower fans. Table 4.3 summarizes the REJ plant information with design conditions, including: boilers, chillers, cooling tower, and pumps. Figure 4.12 shows the main central plant room with cooling towers. Figure 4.13 shows a section of the central plant room of the REJ building. The primary-secondary chilled water loops are used to distribute the chilled water to the REJ building, as shown in Figure 4.14. Variable frequency drives were installed on the secondary chilled water loop. Photos of selected plant equipment in relation to the central plant diagram in Figure 4.15 are shown in Figure 4.16 to Figure 4.21. Two low-NOx boilers and Domestic Hot Water (DHW) heater are also shown in Figure 4.22 and Figure 4.23, respectively.

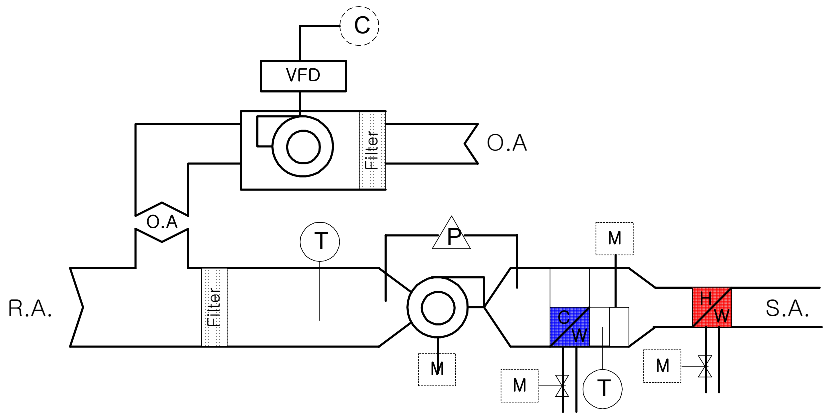


Figure 4.9 *Bypass multi-zone unit for the conference center.*

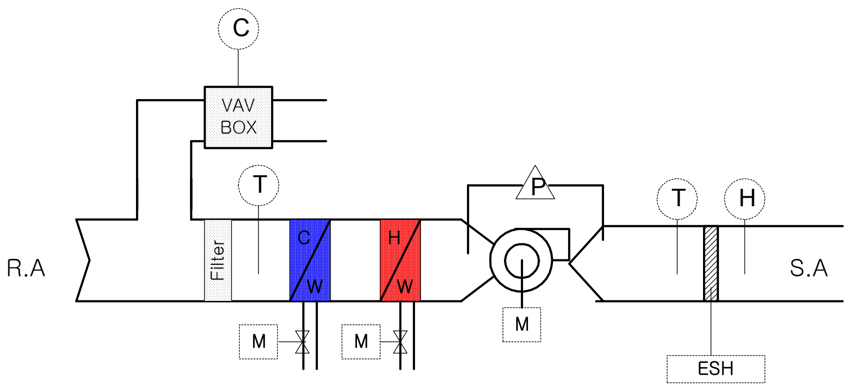


Figure 4.10 *Single-duct Constant Air Volume (CAV) system for the senate print shop.*

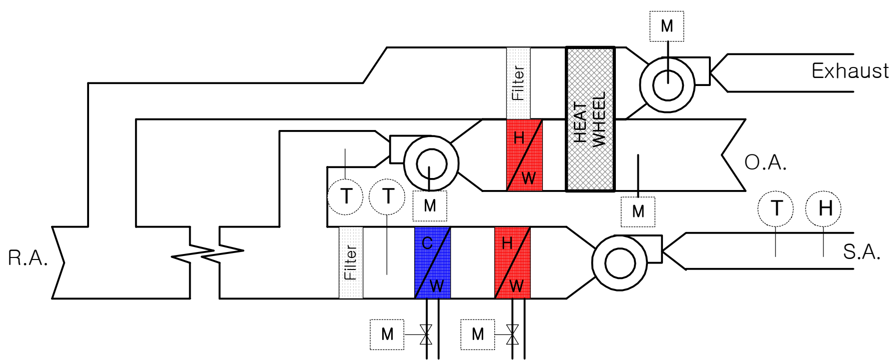


Figure 4.11 *Single-duct Constant Air Volume (CAV) system with heat wheel for the DP print shop.*

T	Temperature Sensor	ESH	Electric Steam Humidifer
C	CO2 sensor	VFD	Variable Frequency Drive
P	Pressure Differential Switch	M	Motor or Actuator

Table 4.3 Plant Information of the REJ Building

Boilers	Mark	Location	Fuel	GPM	Out temp.	HP	Input (Unit)	Output (Unit)	Remarks
	B-1	Central plant	N.G	250	190	0.5	4.98 (MMBtu)	4.185 (MMBtu)	PVI Industries, Inc (125 WBE 250A-TP)
	B-2	Central plant	N.G	250	190	0.5	4.98 (MMBtu)	4.185 (MMBtu)	

Chillers			Chiller data			Condenser data			Input (KW)	Eff. (kw/ton)	Remarks
	Mark	Tons	GPM	EWT	LWT	GPM	EWT	LWT			
	CH-1	465	744	60	45	1395	85	95	251(253)	0.54	TRANE CVHF-555 Centrifugal
	CH-2	465	744	60	45	1395	85	95	251(254)	0.54	
	CH-3	465	744	60	45	1395	85	95	251(255)	0.54	
	CH-4(SB)	74	108	60	45	222	85	95	60	0.85	Screw or recip. CompressorE

Cooling Towers	Mark	Ht.Rej tons	E.W.T	L.W.T	Design WB	GPM	Fan HP(min)	Starter	Total Head	No.cell	Remarks
	CT-1	1000	95	85	80	3000	20	VFD	18'	1	
	CT-2	1000	95	85	80	3000	20	VFD	18'	1	

Pumps	Mark	Serves	Description	GPM	TDH (FT)	RPM	HP	Min. EFF	Starter	Remarks
	CHP-1	CH-1	To Chiller 1	744	20	1150	5	81	DIV. 16	AURORA 340 6x6x9
	CHP-2	CH-2	To Chiller 2	744	20	1150	5	81	DIV. 16	AURORA 340 6x6x9
	CHP-3	CH-3	To Chiller 3	744	20	1150	5	81	DIV. 16	AURORA 340 6x6x9
	BCHP-1	BLDG.	To Bldg.	1232	50	1150	25	87	VFD	AURORA 410 8x8x11B
	BCHP-2	BLDG.(SB)	To Bldg.	1232	50	1150	25	87	VFD	AURORA 410 8x8x11B
	DCHP-1	CH-4	To Chiller 4	108	45	1750	5	87	Stand by	AURORA 340 3x4x11
	DCHP-2	CH-4 (SB)	To Chiller4	108	45	1750	5	87	Stand by	AURORA 340 3x4x11
	CWP-1	CH-1	From Tower	1395	50	1150	25	87	DIV. 16	AURORA 340 6x6x12
	CWP-2	CH-2	From Tower	1395	50	1150	25	87	DIV. 16	AURORA 340 6x6x12
	CWP-3	CH-3	From Tower	1395	50	1150	25	87	DIV. 16	AURORA 340 6x6x12
	DCWP-1	CH-4	From Tower	222	45	1750	5	73	Stand by	Standby
	DCWP-2	CH-4 (SB)	From Tower	222	45	1750	5	73	Stand by	Standby
	BHWP-1	BLDG	To Bldg.	250	35	1750	3	75	VFD	AURORA 340 2.5x3x7B
	BHWP-2	BLDG	To Bldg.	250	35	1750	3	75	VFD	AURORA 340 2.5x3x7B
	HWP-1	B-1	From Boiler	250	15	1750	2	71	DIV. 16	AURORA 340 4x4x7A
	HWP-1	B-2(SB)	From Boiler	250	15	1750	2	71	DIV. 16	AURORA 340 4x4x7A
	GP-1	OA-1	Roof	80	15	1750	0.5	85	DIV. 16	TACO 1L132-3X3
	GP-2	OA-2	Roof	80	15	1750	0.5	85	DIV. 16	TACO 1L132-3X3

Domestic Water Heater(DWH)	Mark	Storage Gal.	Size	Out temp.	Electrical	Recovery Gal/hr	Remarks
	DWH-1, 2, 3, &13	60	9kW	110 F	480/3/60	74 @ 50 F	Electric Storage
	DWH-4 & 5	120	12kW	110 F	480/3/60	98 @ 50 F	Electric Storage
	DWH-7	20	3kW	110 F	120/1/60	24 @ 50 F	Electric Storage
	DWH-10 &12	30	4.5kW	110 F	480/3/60	36 @ 50 F	Electric Storage
	DWH-6,8,9,&11	-	7kW	110 F	277/1/60	1gpm @ 54 F	Instantaneous

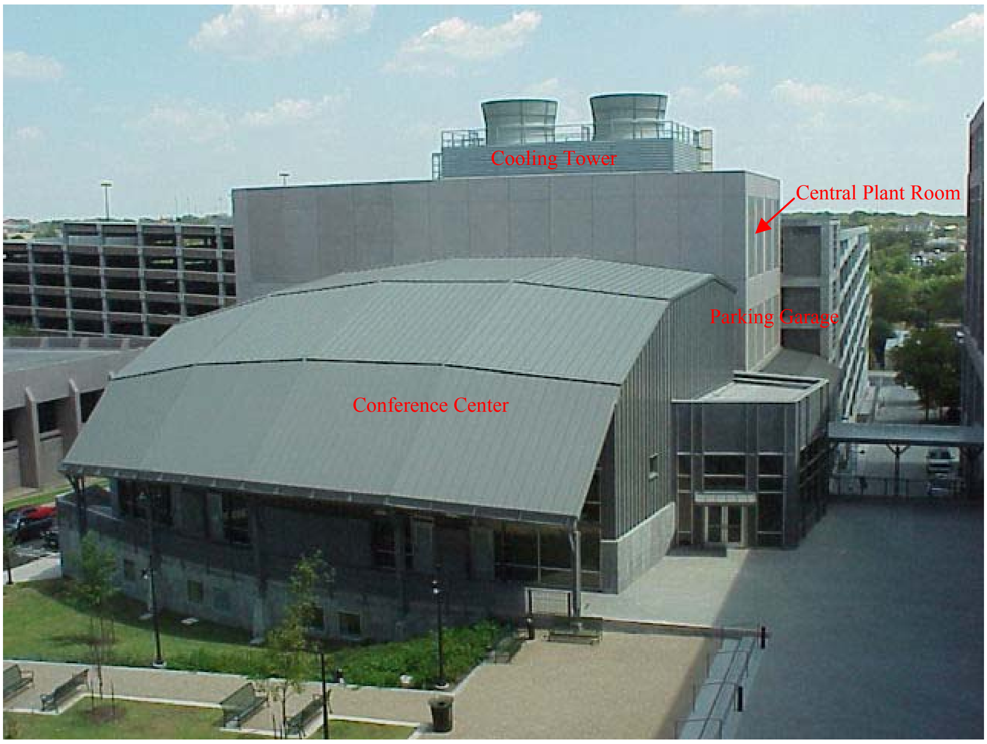


Figure 4.12 *Central plant room in the parking garage.*

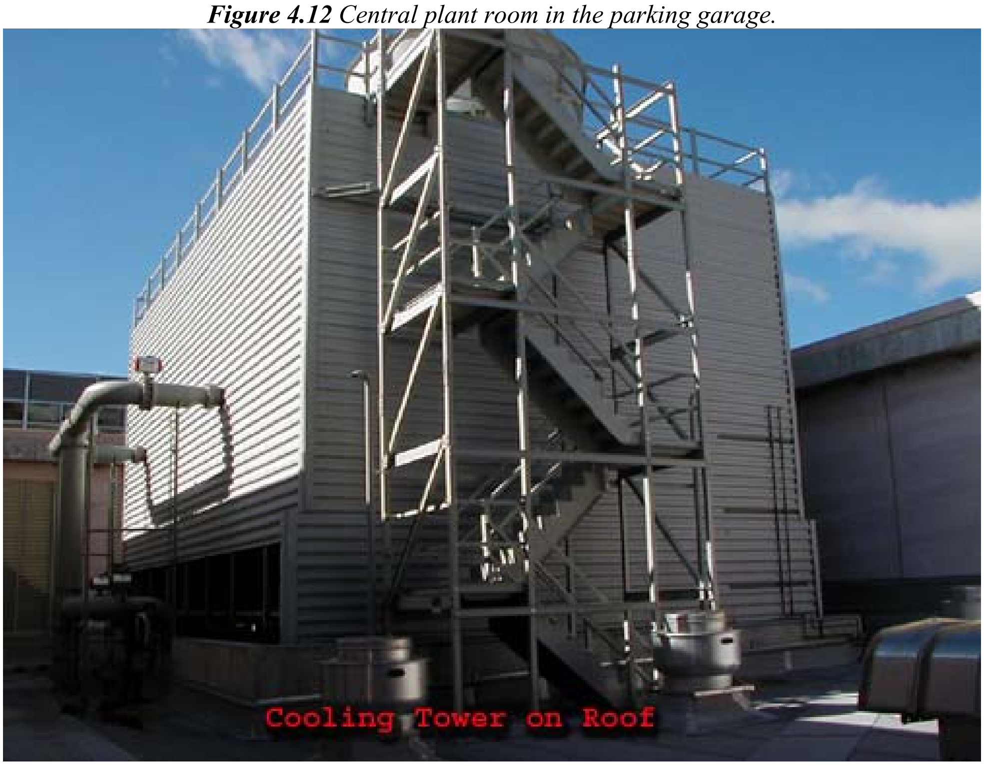


Figure 4.13 *Detailed view of cooling tower on the roof of the parking garage.*

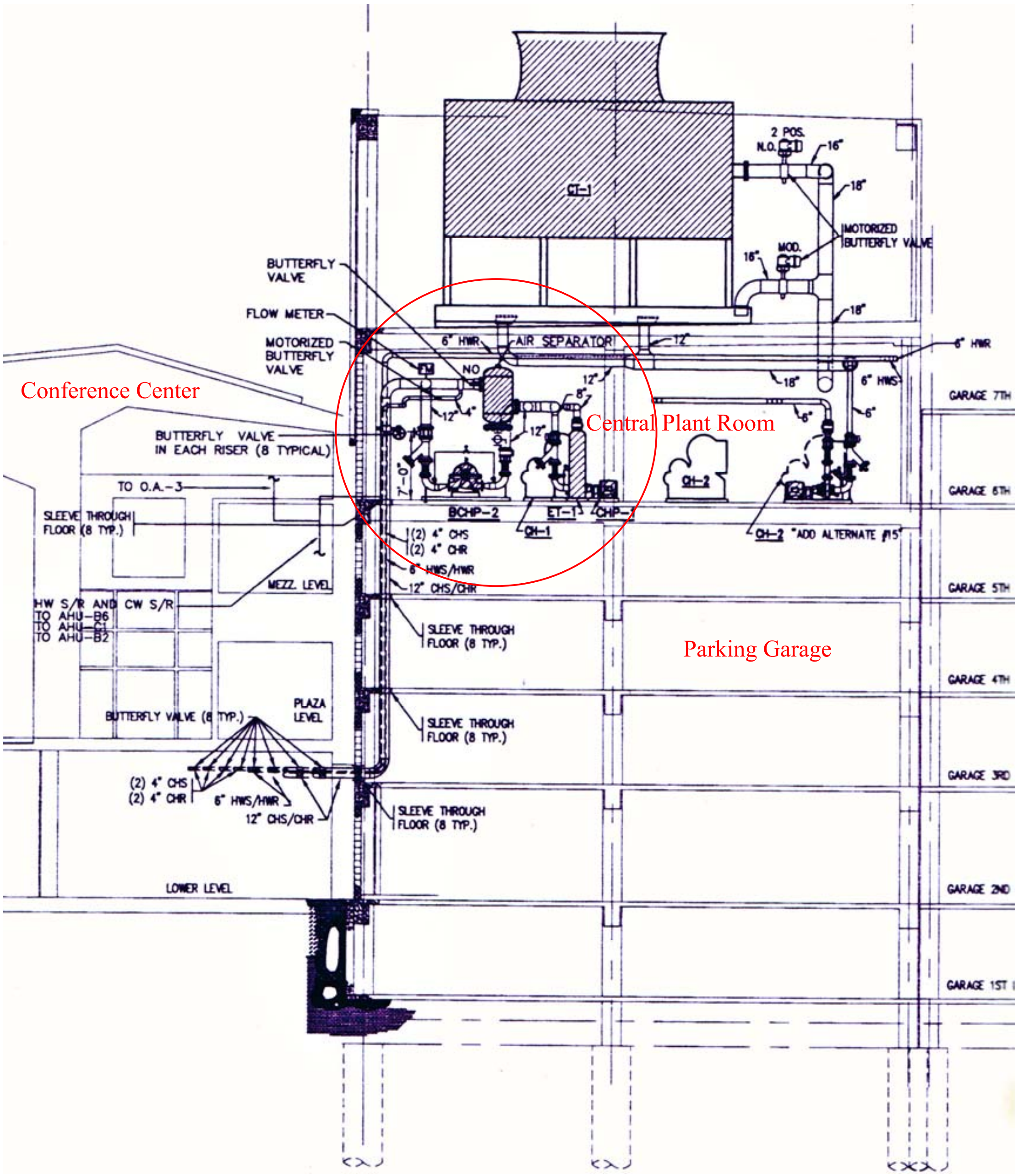


Figure 4.14 *A section of the central plant room in parking garage.*

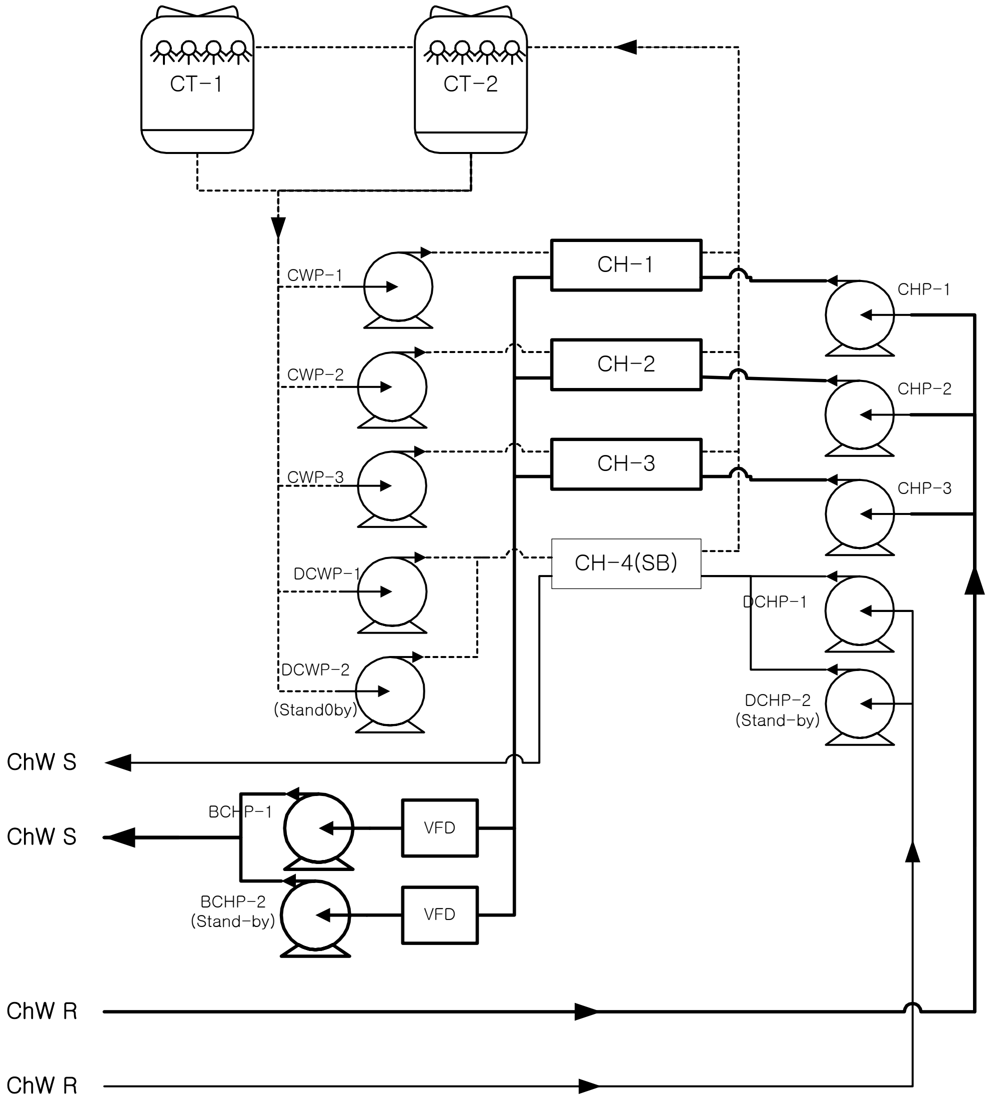


Figure 4.15 *Primary-secondary chilled water and condenser water loop diagram for the REJ building central plant.*

Figure 4.16 *Centrifugal chillers.*
(CH-1,CH-2, and CH-4 in Figure 4.15).

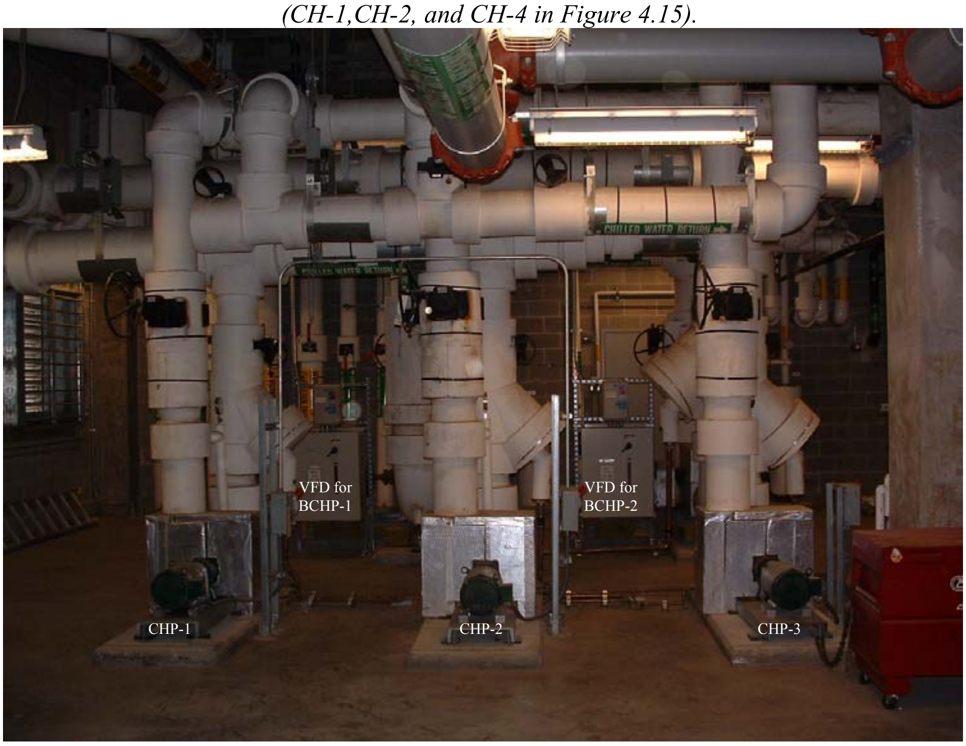


Figure 4.17 *Chilled water pumps and Variable Frequency Drive (VFD) on the secondary loop.*
(CHP-1, CHP-2, and CHP-3 and BCHP-1 and BCHP-2 in Figure 4.15).

Figure 4.18 *Variable Frequency Drive (VFD) on the secondary chilled water loop.*

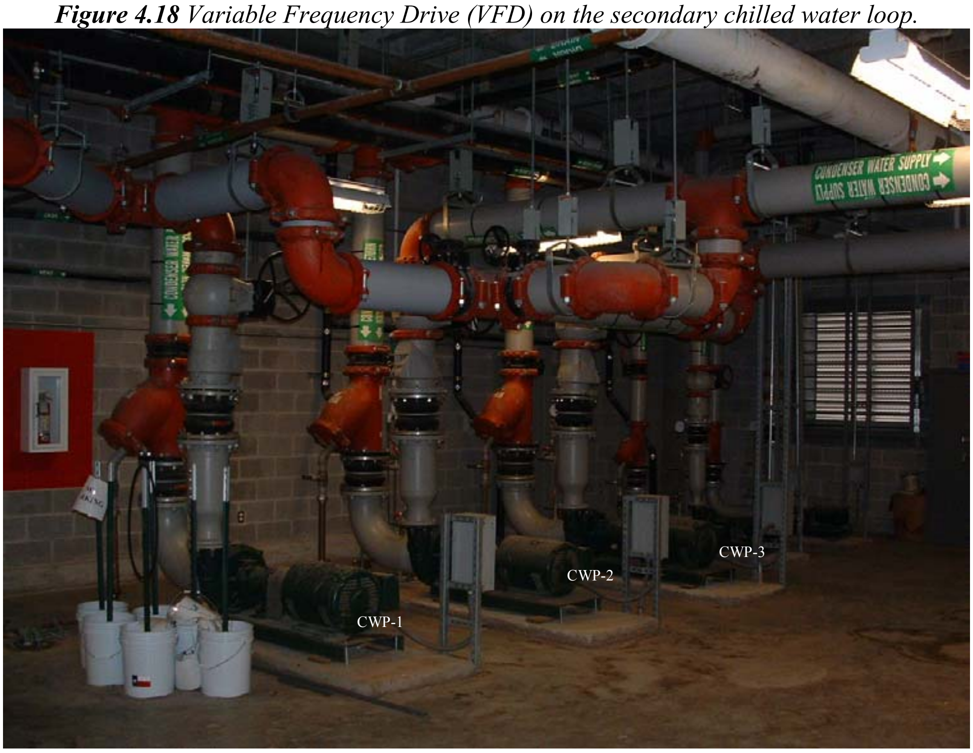


Figure 4.19 *Condenser water pumps for chiller 1, 2, and 3..*
(CWP-1, CWP-2, and CWP-3 in Figure 4.15).

Figure 4.20 *Condenser water pumps for chiller 4.*
(DCWP-1 and DCWP-2 in Figure 4.15).

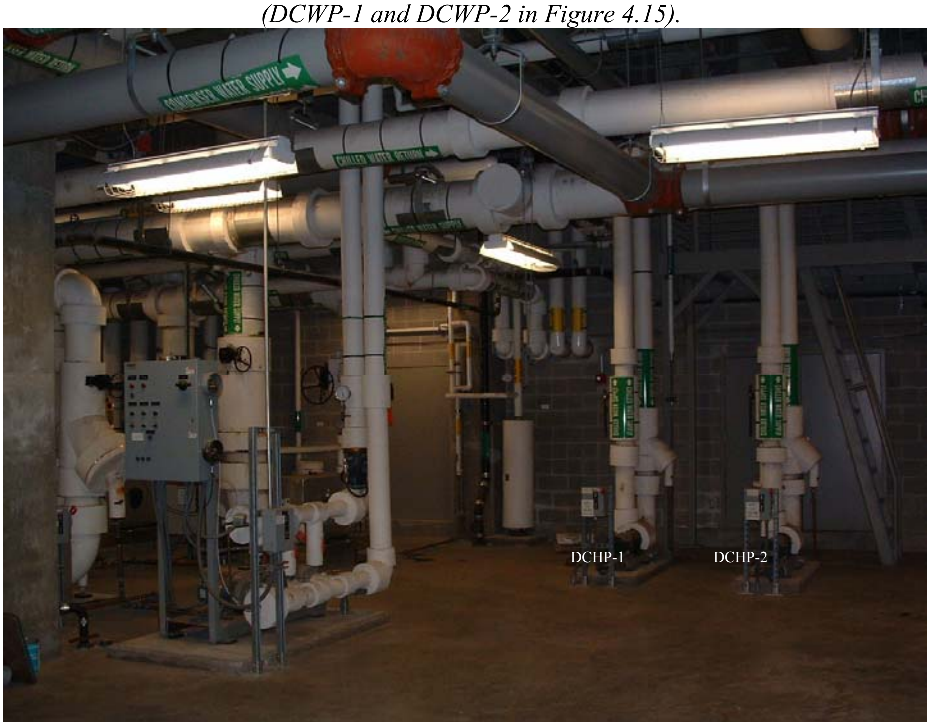


Figure 4.21 *Chilled water pumps.*
(DCHP-1 and DCHP-2 in Figure 4.15).

Figure 4.22 *Low-NOx boilers.*

Figure 4.23 *Domestic Water Heater (DWH).*

4.1.3 Energy Management Control System (EMCS)

The Robert E. Johnson (REJ) state office building is operated by a METASYS Energy Management Control System (EMCS) manufactured by Johnson Controls. Figure 4.24 shows the overall systems diagram controlled by the EMCS for the REJ building. Some of the systems, such as the new chiller (e.g., REJ-CHL3), are not shown on the screen of the EMCS because they were installed after the EMSC installation.

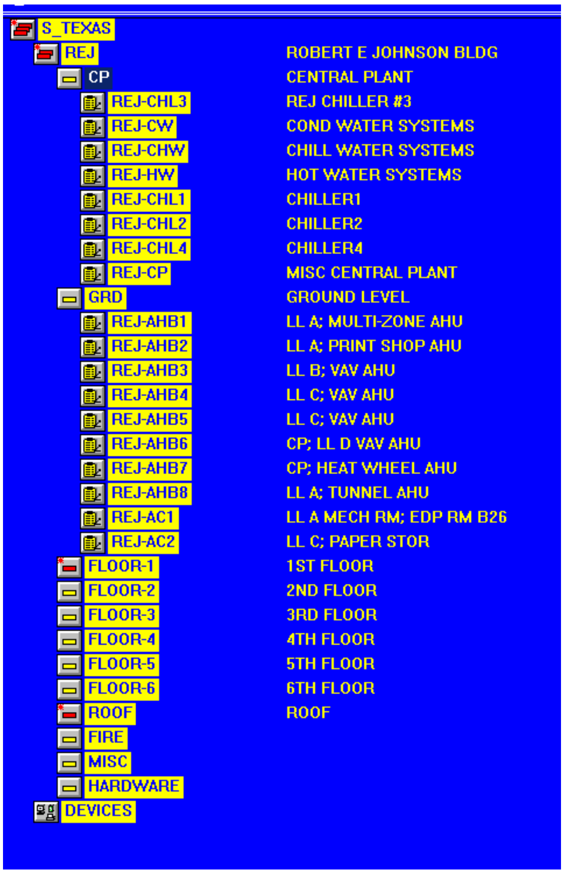


Figure 4.24 *REJ EMCS diagram.*
(Source: Picture taken from the EMCS Monitor).

Figure 4.25 shows the central plant (cp) monitoring diagram and Figure 4.26 shows the hot water systems monitoring diagram taken from the REJ monitoring screen of the EMCS, which monitors and controls some other adjacent buildings.

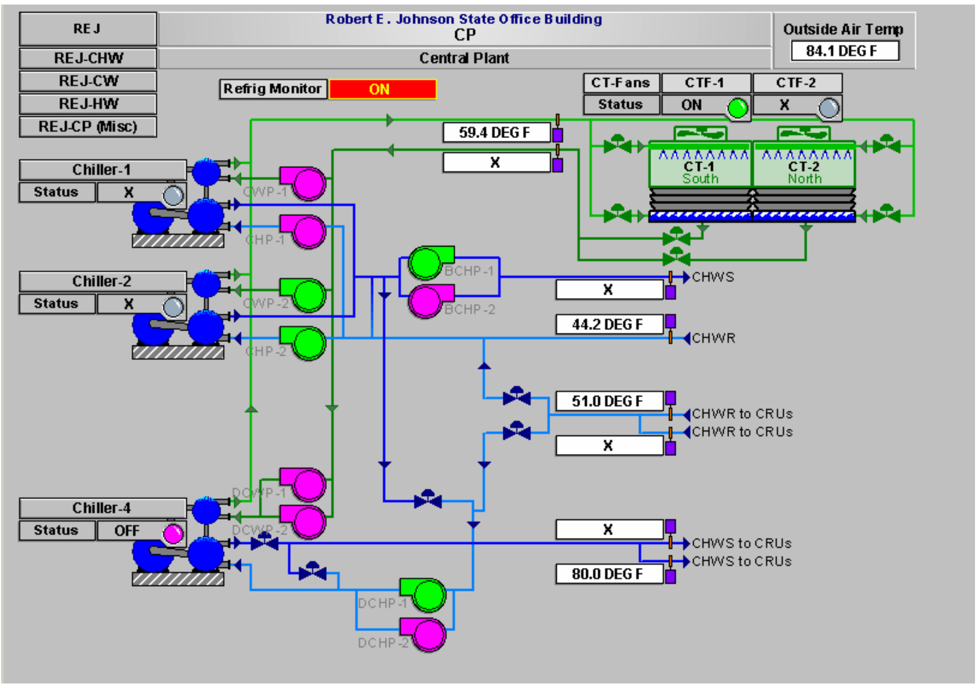


Figure 4.25 *EMCS central plant monitoring diagram.*
(Source: Picture taken from the EMCS Monitor)

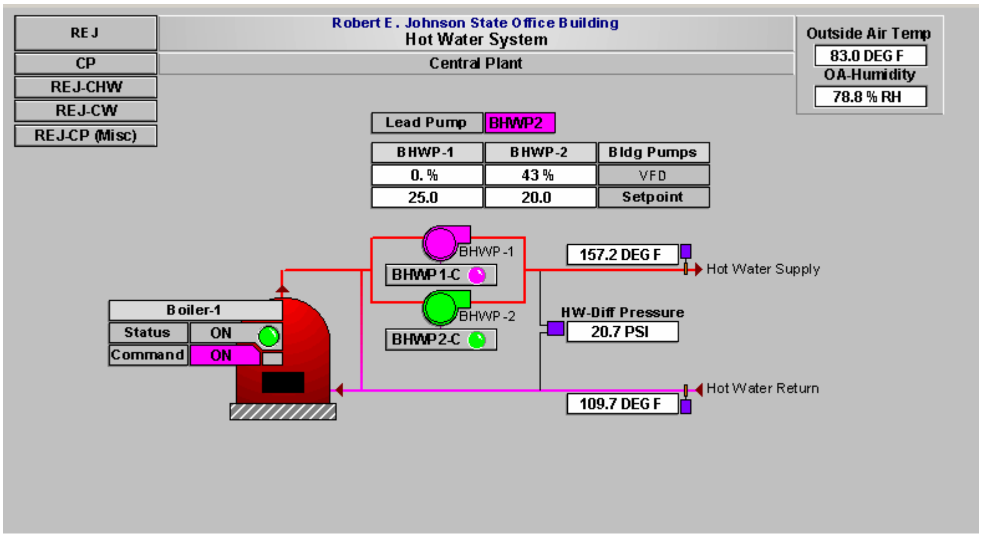


Figure 4.26 *EMCS hot water system's monitoring diagram.*
(Source: Picture taken from the EMCS Monitor)

4.2 Energy Measurement and Verification (M&V)

The Robert E. Johnson (REJ) State office building is a new building with the Energy Conservation Design Measures (ECDMs) as described in Section 4.1. As discussed in Chapter II, Section 2.2, the generic M&V framework in the IPMVP (IPMVP 2003) and Guideline 14 (ASHRAE 2002) was enhanced in this study with detailed M&V methods applicable to new buildings, in terms of whole-building and building component performance. Figure 4.27 shows a schematic M&V framework developed in this study. For the whole-building performance evaluation of the case-study building, measured whole-building end-use EUIs were first compared to similar buildings in a control group, in terms of whole-building electricity (WBE), Motor Control Center (MCC), Lighting and Receptacles (WBE-MCC), Whole-building Cooling (WBC), Whole-building Heating (WBH), and Total Energy Use Indices (EUIs). Second, in-situ measurements and/or manufacturer's performance data were applied to the as-built simulation model in order to account for actual performance of each system, including plant, AHU systems, and building envelope. In this study, selected components such as a high efficiency chiller, dual-duct AHU, and low-e glazing were measured to verify the actual performance of each component. Finally, the simulation results from the as-built simulation were compared to energy baselines, such as a code-compliant baseline with Standard 90.1-1989 vs. Standard 90.1-2001, and a design baseline without Energy Conservation Design Measures (ECDMs). Detailed methods for the case-study building are described in the following Sections, including how to develop energy baselines, how to measure whole-building and component energy performance, and how to simulate and calibrate the case-study building.

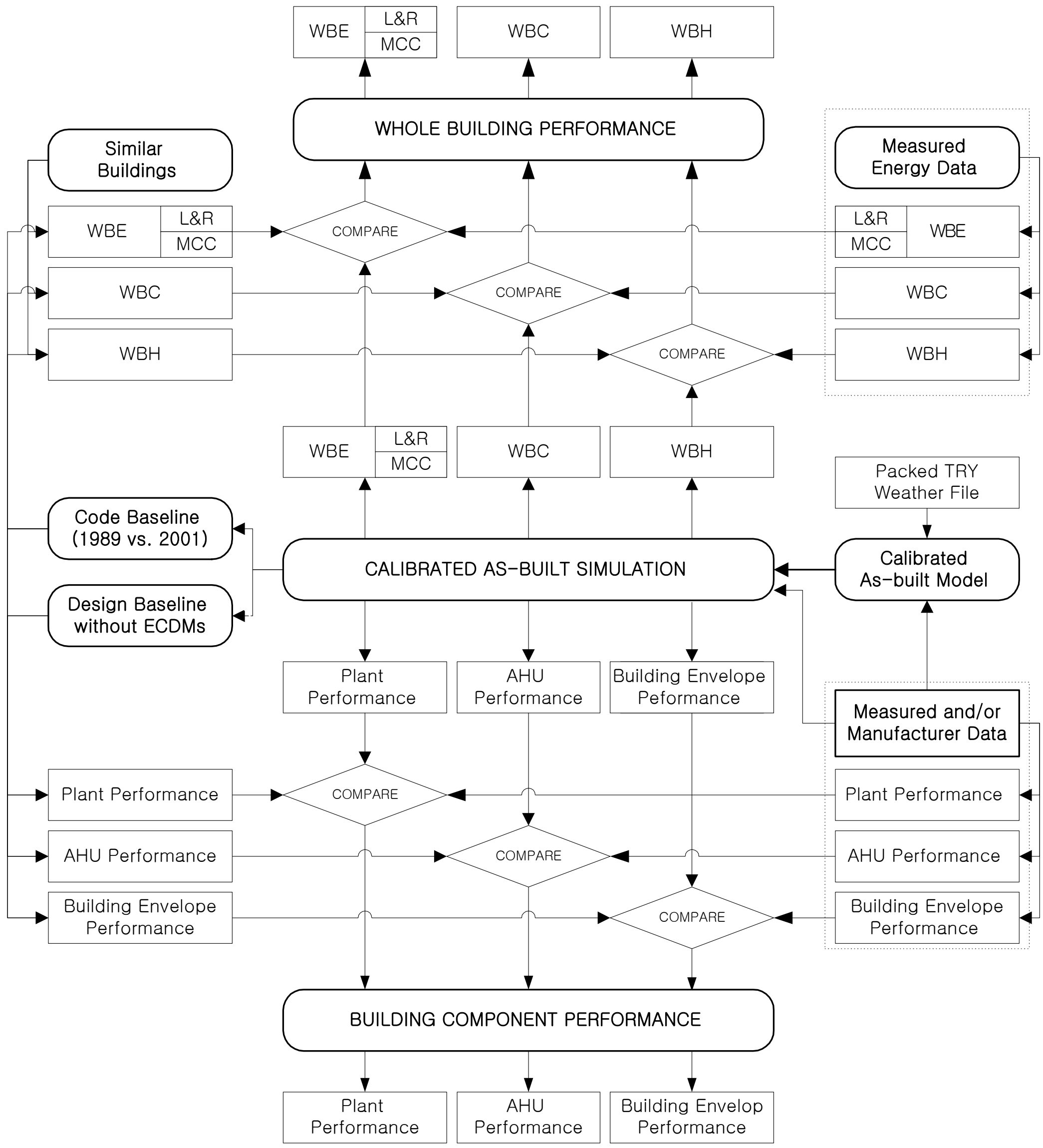


Figure 4.27 *A schematic M&V method developed for the case-study building.*

4.3. Baselines for Building Energy Use

Energy savings in an energy efficient new building can be calculated as the difference between the energy uses predicted by a baseline (e.g., a simulation model or a regression model) and measured as-built energy data. The methods of developing the energy use baselines used in this study are described in the following Sections, including: Energy Use Indices (EUIs), change-point linear models, and code-baselines (e.g., simulation models) compliant with ASHRAE Standard 90.1-1989 and 2001.

4.3.1 Building Energy Use Indices (EUIs)

Energy use indices (EUIs) have been used as an indicator of energy efficiency for quick comparison to other reference buildings. Most EUIs express annual total energy use per square foot of conditioned area (CBECS 1999). In this study, the indices were disaggregated into energy end use such as whole-building electricity (WBE), whole-building heating (WBH), whole-building cooling (WBC), motor control center (MCC), and lighting and receptacle (L&R), and then compared to those from other similar buildings in a control group (Haberl et al. 2001) as shown in Table 4.4, which includes the annual total EUIs for 12 office buildings in Austin, Texas.

Table 4.4 Energy Use Indices (EUIs) for Similar Buildings in Austin, Texas

No.	Building Name	Building area(sqft)	Measured Periods		Energy Use indices (EUIs)	
			Start date	End date	kWh/ft2-yr	kBtu/ft2-yr
1	REJ building	303,389	1/1/01	12/31/01	36.11	123.21
2	John H. Reagan building	169,746	1/1/97	12/31/97	37.55	128.12
3	Insurance building	102,000	1/1/96	12/31/96	48.75	166.34
4	Archives building	120,000	1/1/97	12/31/97	29.29	99.94
5	W.B. Travis building	491,000	1/1/97	12/31/97	38.29	130.65
6	L.B. Johnson building	308,080	1/1/97	12/31/97	-	-
7	Price Daniels building	151,620	1/1/98	12/31/98	35.65	121.64
8	Tom C. Clark building	121,654	1/1/98	12/31/98	30.23	103.14
9	Capitol building	282,499	7/1/97	7/1/98	40.49	138.15
10	Sam Houston building	182,961	1/1/93	12/31/93	50.77	173.23
11	James E. Rudder building	80,000	1/1/94	12/31/94	66.60	227.24
12	Insurance Annex building	62,000	1/1/93	12/31/93	32.99	112.56

(Source: Haberl et al., 2001)

Weekday and weekend diversity factors (Haberl et al. 2001) were used to derive the EUIs as one of the effective ways based on an analysis developed for ASHRAE's Research Project 1093-RP that uses percentiles, where the 10^{th}, 25^{th}, 75^{th}, and 90^{th} percentiles are reported for each hour of the day by daytype such as weekday and weekend (Abushakra et al. 2001). The 1093-RP diversity factor calculation contains several spreadsheets required for data processing steps, which are presented later in Section 4.5.3. The EUI (kWh/ft^2 year) used in this study is calculated using the daily total for weekdays and weekends using the following formula:

$$EUI = \frac{\left[(Weekday\ Daily\ Mean\ Value \times 5) + (Weekend\ Daily\ Mean\ Value \times 2)\right] \times 52 \times PeakW/ft^2}{1000} \quad (4\text{-}1)$$

Where, *Weekday Daily Mean Value* is a dimensionless value obtained by dividing the weekday daily mean by the absolute maximum hourly value in the weekday maximum profile.

Weekend Daily Mean Value is a dimensionless value obtained by dividing the weekend daily mean by the absolute maximum hourly value in the weekend maximum profile.

4.3.2 Change-Point Linear Regression Models

As discussed in Section 2.2, the IMT provides several types of regression models. Table 4.5 describes the types of models supported by the IMT toolkit. Figure 4.28 illustrates the models in Table 4.5, which are identified by the number of regression coefficients β. The ( )+ and ( )$^-$ notations indicate that the values of the parenthetic term shall be set to zero when they are negative and positive, respectively.

Table 4.5 IMT Change-point Linear Models

Model Name	Equation Models	Description
2P Model	$Y = \beta_1 + \beta_2 X_1$	Where β_1 and β_2 are regression coefficients
3P Model	$Y_c = \beta_1 + \beta_2 (X_1 - \beta_3)^+$ $Y_h = \beta_1 + \beta_2 (X_1 - \beta_3)^-$	Where β_1 is the constant term, β_2 is the slope term, and β_3 is the change-point
4P Model	$Y = \beta_1 + \beta_2 (X_1 - \beta_4)^- + \beta_3 (X_1 - \beta_4)^+$	Where β_1 is the constant term, β_2 is the left slope, β_3 is the right slope, and β_4 is the change point.
5P Model	$Y = \beta_1 + \beta_2 (X_1 - \beta_4)^- + \beta_3 (X_1 - \beta_5)^+$	Where β_1 is the constant term, β_2 is the left slope, β_3 is the right slope, β_4 is the left change-point, and β_5 is the right change-point.
Multi variable Regression Model	$Y = \beta_1 + \beta_2 X_1 + \beta_3 X_2 + \beta_4 X_3 + \beta_5 X_4 + \beta_6 X_5 + \beta_7 X_6$	Where β_1 through β_7 are regression coefficients, and X_1 through X_6 are independent variables
VBDD Model	$Y = \beta_1 + \beta_2 HDD(\beta_3)$ $Y = \beta_1 + \beta_2 CDD(\beta_3)$	Where β_1 is the constant term, β_2 is the slope term, and $HDD(\beta_3)$ and $CDD(\beta_3)$ are the number of heating and cooling degree-days, respectively

IMT can find best-fit models according to the number of change-points. 2P models are appropriate for modeling building energy use that varies linearly with a single independent variable. 3P models are appropriate for modeling building energy use that varies linearly with one independent variable over part of the range of the independent variable and remains constant over the other range, which is founded in a building with thermostatic control. Five-parameter models using outdoor air temperature as the independent variable are appropriate for modeling energy consumption data that includes both heating and cooling, such whole-building electricity data from buildings with electric heat pumps or both electric chillers and resistance heating. They are also appropriate for modeling fan electricity consumption in variable-air-volume systems.

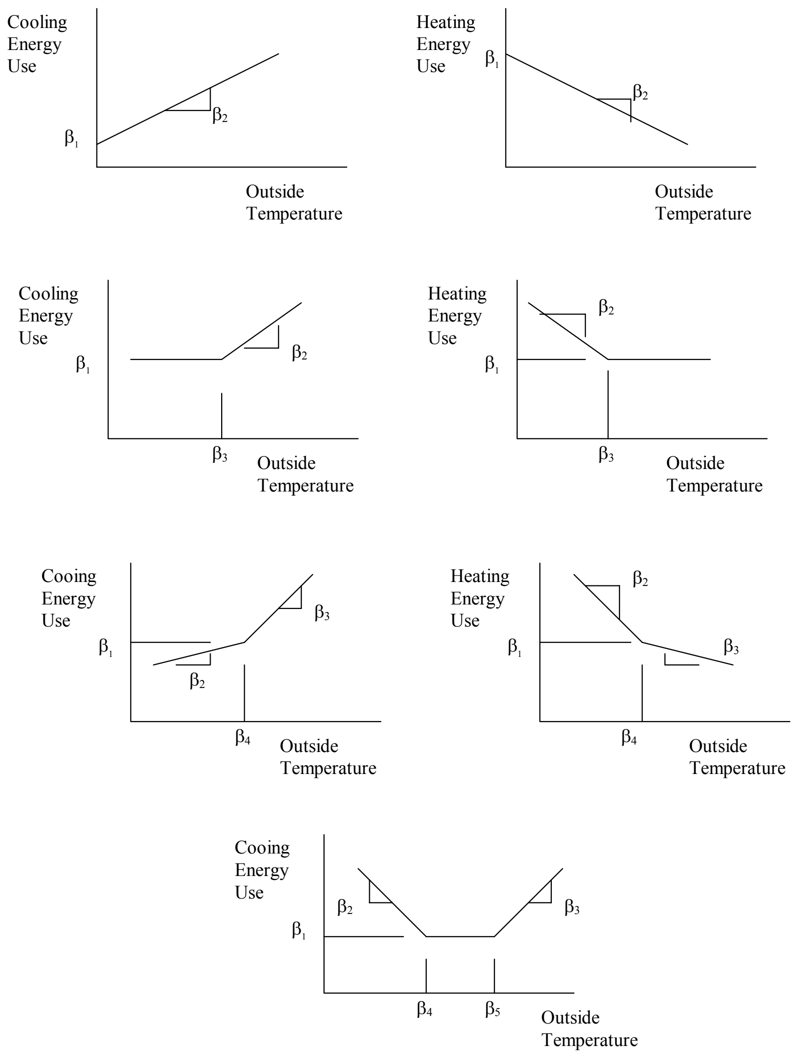


Figure 4.28 *IMT change-point linear models (Kissock et al. 2001).*

A new chiller was added as a third chiller to the case-study building without any additional supply and return temperature sensors to measure cooling energy use. Therefore, the 2004 cooling energy use was synthesized in this study using the IMT 4P change-point linear model as shown in Figure 4.29. The 4P change-point linear cooling model was derived from a correlation of ChW energy use and MCC electricity use as illustrated in Figure 4.30 and Figure 4.31. Section 5.2.5 in Chapter 5 shows the cooling energy use synthesized using the 4P change-point linear developed in this study.

```
ASHRAE INVERSE MODELING TOOLKIT (1.9)
********************************************
   Output file name = IMT.Out
********************************************
   Input data file name =  rej_cm01.dat
   Model type =         4P
   Grouping column No =   0
   Value for grouping =   0
   Residual mode =        0
   # of X(Indep.) Var =   1
   Y1 column number =    4
   X1 column number =   5
   X2 column number =   0 (unused)
   X3 column number =   0 (unused)
   X4 column number =   0 (unused)
   X5 column number =   0 (unused)
   X6 column number =   0 (unused)
********************************************
   Regression Results
  --------------------------------------
        N =    322
  --------------------------------------
       R2 =       0.976
  --------------------------------------
    AdjR2 =      0.976
  --------------------------------------
     RMSE =   5189.7505
  --------------------------------------
   CV-RMSE =     4.153%
  --------------------------------------
        p =      0.643
  --------------------------------------
       DW =      0.714 (p>0)
  --------------------------------------
       N1 =     83
  --------------------------------------
       N2 =    239
  --------------------------------------
      Ycp =  97762.3672 (   4679.5039)
  --------------------------------------
       LS =     12.4604 (      0.4892)
  --------------------------------------
       RS =     24.6652 (      0.8821)
  --------------------------------------
      Xcp =    6727.3584 (    131.3866)
```

Figure 4.29 *An example of IMT results for 4P change-point linear model.*

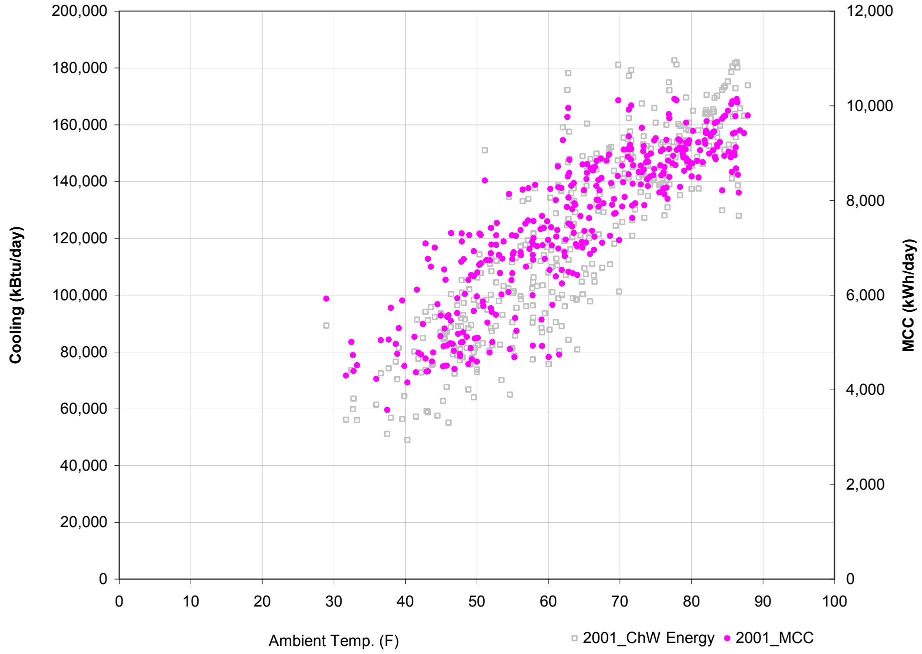


Figure 4.30 *X-Y scatter plot of 2001 measured daily cooling energy use and 2001 Motor Control Center (MCC) electricity use against dry-bulb temperature.*

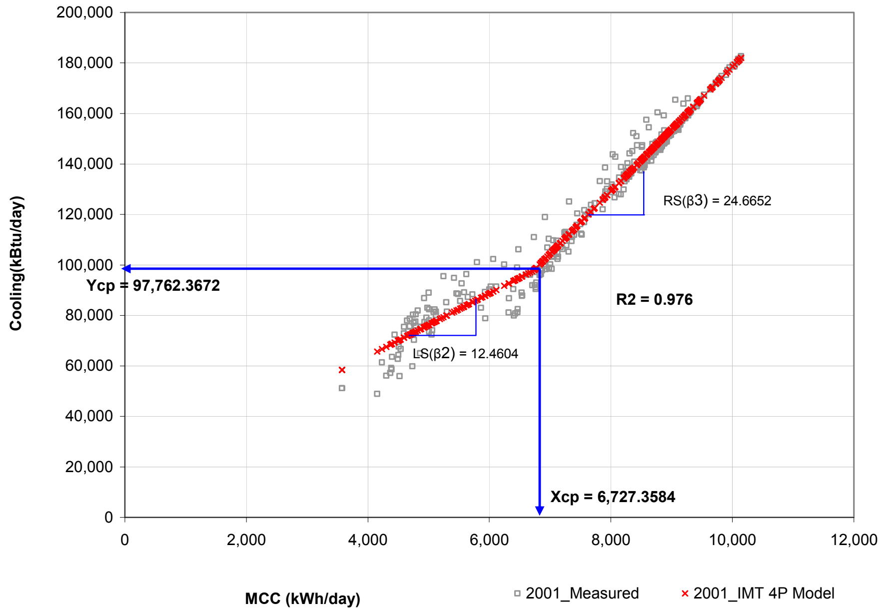


Figure 4.31 *4P Change-point model used to compare measured 2001 daily cooling energy use against Motor Control Center (MCC) electricity use.*

4.3.3 Code Baselines Compliant with ASHRAE Standards 90.1-1989 and 2001

As described in Chapter II, ASHRAE Standard 90.1-1999 contains numerous improvements over the 1989 version, along with enhanced energy efficiency levels. The 2001 version includes the entire 1999 version, along with 34 new addenda. In this study, a comparative assessment will therefore be performed to calculate energy savings based on the code-baselines compliant with the Standard 90.1-1989 and 2001. Both Standard 90.1-1989 and 2001 provide the Energy Cost Budget (ECB) method as an alternative compliance path. According to the definition about code compliance in Standards 90.1-1989 and 2001, a proposed design complies with the Standard 90.1 if the Design Energy Cost (DEC) is not greater than the ECB and all of the basic requirements are met. Unfortunately, the ECB method is not intended to predict or verify actual energy consumption or cost due to variations such as occupancy, building operation and maintenance, weather, energy use not covered by the standard, and precision of the calculation tool (ASHRAE 2004). Thus, the code baselines used in this study were developed to account for the actual as-built conditions by modifying the calibrated as-built simulation model, which is described in Chapter VI. The following sub-sections describe the 1989 and 2001 ECB models developed in this study, in terms of building shape, building envelope, internal loads, and HVAC systems and equipment efficiency.

4.3.3.1 Building Orientation and Shape

The 1989 budget model is rectangular shaped with an aspect ratio of 2.5 to 1.0 with one longer side facing east and west, while the 2001 budget model has the same exterior dimensions and orientation as the proposed design. Both the 1989 and 2001 budget models have the same number of stories and gross floor area for each story as the proposed design. Table 4.6 compares building shape between Standard 90.1-1989 and the 2001 budget model.

Table 4.6 Comparison of Building Shape between the 90.1-1989 and 2001 Models

Items	1989 Budget Model	2001 Budget Model	Remarks
Building Shape	Rectangular in shape with an aspect ratio of 2.5 to 1.0		
Floor Area	Same as proposed design	Same as proposed design	-
Floor to Floor Height	13 ft		

Table 4.7 specifies the building geometry for the 90.1-1989 budget model used in this study. The geometry was recalculated from the as-built simulation for the case study building, except for the floor to floor height in the 90.1-1989 model, which is fixed as a prototype building in the Standard 90.1-1989. Figure 4.32 presents the typical floor plan and elevation for the 90.1-1989 budget model used in this study. The 90.1-2001 model geometry is identical to the as-built simulation model described in Chapter 6.

Table 4.7 Building Geometry for the 90.1-1989 Budget Model

Building Geometry	1989 Budget Model	Remarks
Building Azimuth	14 degree	
Length of Building	355.35 ft	
Width of Building	142.14 ft	
Floor to Floor Height	13 ft	Fixed in the Standard 90.1-1989
Number of Floor	6 ft	
Perimeter Depth	15 ft	

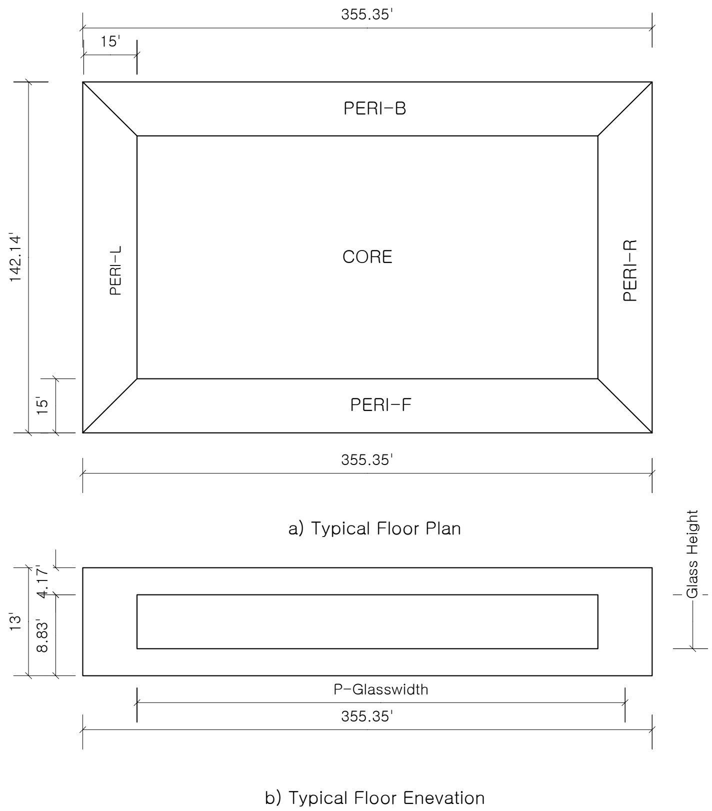


***Figure 4.32** Typical floor plan and elevation of the 90.1-1989 budget model.*

4.3.3.2 Building Envelope

Table 4.8 compares the building envelope description in the Standard 90.1-1989 and 2001 models. In the 90.1-2001 model, the opaque assemblies have the same heat capacity as the proposed design, but with the minimum U-factors, while the 90.1-1989 model requires minimum U-factors according to the Alternate Component Table (ACP) for each climate zone. The 1989 ACP table provides a maximum allowable percentage of window area as a function of internal load density (ILD), projection factor (PF), shading coefficient (SC), and window U-factor.

Table 4.8 Comparison of Building Envelope Description in the 90.1-1989 and 2001 Models

Items	1989 Budget Model	2001 Budget Model	Remarks
Opaque Assemblies	U-factors selected from the 1989 ACP table for the appropriate climate, with light weight walls	The same heat capacity as the proposed design but with the minimum U-factors required for new buildings	Roof, floors, doors, and wall
Roof Albedo	Absorptivity of 70 %	Reflectivity of 0.3	-
Fenestration	Shading coefficient of 0.7 No requirements of minimum U-factor and maximum SHGC	Minimum U-factor required for the climate and maximum heat gain coefficient (SHGC) allowed for the climate and orientation	From Window 5 for the proposed design model
Fenestration Area	Maximum allowable Percent selected from the 1989 ACP table for the appropriate climate	Same as proposed design	Uniformly distributed in proportion to exterior wall area
Interior Shading	Draperies closed one-half time	Same as proposed design	-
Shading	Shading by permanent structure, terrain, and vegetation	Same as proposed design	Trees and adjacent buildings
Infiltration	No infiltration when HVAC is on, 0.38 cfm/sqft of exterior wall when HVAC is off. Only perimeter zones	In accordance with NFRC 400 (Air leakage)	-

Table 4.9 shows the 90.1-1989 and 2001 envelope model developed for the case study building located in Austin, Texas (HDD65= 1688 and CDD50= 7171), which is from the ACP Table 8A-12 in the Standard 90.1-1989 and Table B-6 (HDD65= 901-1800, CDD50= 5401-7200) in the Standard 90.1-2001. The minimum U-factor was used for each construction in the 90.1-1989 model, which doesn’t account for the heat capacity of construction. For the 90.1-2001 model, the Custom Weighting Factor method was used to account for thermal mass effect in DOE-2 simulation. Insulation in the construction layer was adjusted for the same heat capacity with minimum U-Value as the proposed as-built model because

insulation is relatively lower heat capacity than other materials. U-effective was also calculated for underground walls and floors, which is described in Section 4.5.4. On the other hand, the 90.-1989 model defines 15% of maximum allowable percentage of window-to-wall ratio from the 1989 ACP Table 8A-12. A 51.75% of window-to-wall ratio was used for the 90.1-2001 model because it is not much higher than the 50% of maximum allowable percentage in the 90.1-2001.

Table 4.9 Comparison of Building Envelope between the 90.1-1989 and 2001 Models for Austin, Texas (HDD65: 1688 and CDD50: 7171)

Measures		1989 Budget Model	2001 Budget Model	Remarks
Roof Absorptance		0.7	0.7	-
Construction		Minimum U-factor	Minimum U-factor	As-built conditions
Roof	Type 1	0.058	0.063 (0.063)	0.041
	Type 2			0.054
Exterior Wall	Type 1	0.15	0.124 (Steel frame) (0.128)	0.057
	Type 2			0.056
Interior Wall		Same as proposed design	Same as proposed design	0.414
Ceiling		Same as proposed design	Same as proposed design	0.858
Floor		0.11	0.137	0.105
Underground Floor		Same as proposed design	Same as proposed design	U-effective (0/001)
Underground Wall		Same as proposed design	Same as proposed design	U-effective (0.048)
Thermal Mass		Pre-calculated Factor	Custom Weighting Factor	For the same heat capacity as the proposed design, custom weighting factor was used for the 90.1- 2001 budget model
Floor-Weight		70 lb/sqft	0	
Furniture-Type		-	Light	
Furniture Fraction		-	0.5	
Furniture-Weight		-	8 lb/sqft	
Window-to-Wall Ratio (%)		15%	51.75 %	Uniformly distributed in proportion to exterior wall area Maximum percent from the ACP table for the 90.-1980 model
Front (South)		15%	50 %	
Right (East)		15%	53 %	
Back (North)		15%	54 %	
Left (West)		15%	50 %	
Glass Type				Lower/Upper
U-factor		1.22	1.22 (Fixed)	0.31 / 0.29
Shading Coefficient		0.7	0.20 / 0.49 (SHGC/0.86)	0.32 / 0.44
SHGC		0.61	0.17 (All), 0.42(North)	0.28 / 0.38

(Note: From ACP Table 8A-12 in the Standard 90.1-1989 and Table B-6 (HDD65:901-1800, CDD50:5401-7200) in the Standard 90.1-2001).

4.3.3.3 Internal Loads

Interior Lighting Power Density (ILPD) is determined according to gross lighted area of total building or space active areas in the 1989 Standard, whereas the building area method and the space-by-space method are provided to calculate Interior Lighting Power Allowance (ILPA) in the 2001 Standard. Table 4.10 compares the internal loads selected from the Standards 90.1-1989 and 2001 for the case study building, including: lighting, receptacle, and occupancy density and schedules. In order to calculate actual energy savings compared to both Standards, the same building schedules as proposed as-built model were used in this study for both the Standard 90.1-1989 and 2001 budget models even though Standard 90.1-1989 provides prototype building schedules.

Table 4.10 Comparison of Internal Loads between the Standard 90.1-1989 and 2001 Models

Items	Energy Cost Budget (ECB) Model		
	1989 Budget Model	2001 Budget Model	Remarks (As-built conditions)
Lighting	1.5 ULPA (W/sqft)	1.3 (W/sqft) LPD	Office
Receptacles	0.75 W/sqft	Same as proposed design	-
Occupancy	275 sqft/person	Same as proposed design	230 sensible and 190 latent
Schedules	Same as proposed design	Same as proposed design	Measured data

(Note: Table 9.3.1.1 in the Standard 90.1-2001 and Table 6-3, Table 6-5, Table 13-1, and Table 13-4 in the Standard 90.1-1989).

4.2.3.4 HVAC System and Equipment

Table 4.11 compares HVAC systems descriptions between Standards 90.1-1989 and 2001, including: HVAC systems type and control, thermal block zoning, and equipment sizing and efficiency.

4.2.3.4.1 HVAC System Type and Control

Table 4.12 shows the 90.1-1989 system number for an office building according to total conditioned area or total floor area. For the case study building, System Number 5 was determined by floor area (about 300,000 sqft) and total stories (six floors and a basement). In the 2001-90.1 model, the HVAC system maps are used to select the appropriate HVAC systems based on condenser cooling source, heating system classification, and building type. Table 4.13 shows the 2001 code-compliant systems with water-type condenser cooling source applicable to the case study building. For the case study building, System Number 2 was determined based on the HVAC system map in the 2001-90.1 code. Table 4.14 describes the HVAC systems operation requirements compliant with the Standard 90.1-1989 and 2001.

Table 4.11 Comparison of HVAC Systems Descriptions for the Standard 90.1-1989 and 2001 Models

Items	1989 Budget Model	2001 Budget Model	Remarks
HVAC System Type	Based on total conditioned area and/or total floor area	Based on HVAC systems map	-
Thermal Blocks	One zone per floor and at least four perimeters with 15' width	Same as proposed design	
HVAC Equipment Size	Sized with the load calculation procedure described in the 1989 Standard using sizing runs loop	Sized proportionally to the capacities in the proposed design using sizing runs loop	Figure 4.33 (1989 sizing loop) Figure 4.34 (2001 sizing loop)
HVAC Equipment Efficiency	1989 minimum requirement	2001 minimum requirement	-
HVAC Control	1989 minimum requirement	2001 minimum requirement	-

Table 4.12 HVAC System Model for Office in the Standard 90.1-1989

Building/Space occupancy	System No.	Remarks
2. Office		
a. $\leq$20,000 ft^2	1	Packed rooftop single zone, one unit per zone
b. >20,000 ft^2 and either $\leq$ 3 floors or $\leq$ 75,000 ft^2	4	Packed rooftop VAV with perimeter reheat
c. 75,000 or > 3 floors	5	Built-up central VAV with perimeter reheat

(Note. Table 13-5 in ASHRAE Standard 90.1-1989).

Table 4.13 HVAC Systems for the Case Study Building in the Standard 90.1-2001

System Type		Fan Control	Cooling Type	Heating Type
1	VAV with parallel fan-powered boxes (note 1)	VAV	Chilled Water	Electric Resistance
2	VAV with reheat (note 2)	VAV	Chilled Water	HW Fossil Fuel Boiler

(Note. Table 11.4.3 A in ASHRAE Standard 90.1-2001).

4.2.3.4.2 HVAC Equipment Size, Type and Number, and Efficiency

According to Standard 90.1-1989 and 90.1-2001, the chiller plant of budget building design should be modeled with the number as a function of total chiller plant loads and type as a function of individual chiller loads as specified in Table 4.15 and Table 4.16, respectively.

Table 4.14 Comparison of HVAC Systems Operation Requirements in the Standards 90.1-1989 and 2001

HVAC Component	1989 Budget Model	2001 Budget Model
Minimum Flow Rate	4.5 air changes/hr or 15 cfm/person	0.4 cfm/sqft
Supply Fan	4 in. wc of total static pressure and 55% of total efficiency	If supply, return, or relief fan has a motor 25hp or larger, a Variable Speed drive shall be modeled. For smaller fan, a forward-curved centrifugal fan with inlet vanes shall be modeled.
Supply Fan Control	Air-foil centrifugal fan and VFD	
Chilled Water Temp.	44F supply water temp. Reset supply temp. by at least 25% of the design supply-to-return water temperature diff. If chiller design capacity exceeds 600,000Btu/h,	44F supply and 56 F return water temp. Automatically reset supply temp. by representative building loads or by outside air temp. if chiller design capacity exceeds 300,000Btu/h.
Chilled Water Pumps	12 F temp. rise from 44 F to 56 F, Operating at 75ft of head and a 65% combined impeller and motor efficiency	Same as proposed design pump power.
Condenser Water Pumps	10 F temp. rise operating at 60ft of head and a 60% combined impeller and motor efficiency	Same as proposed design pump power.
Cooling Tower	Open circuit with centrifugal blower sized for the larger of 85 F condenser water design temperature or 10 F approach to design WB temp.	Axial fan cooling tower with two speed fan. 85 F condenser water design temperature or 10 F approach to design WB temp.
Tower Control	65F leaving water temp. whenever weather conditions permit, floating up to the design leaving water temp. at design condition	70F leaving water temp. where weather permits, floating up to the design leaving water temp. at design condition
Hot water Temp.	180 F design supply and 130 F return hot water temperature. Reset supply temp. by at least 25% of the design supply-to-return water temperature diff. if chiller design capacity exceeds 600,000Btu/h	180 F design supply and 130 F return hot water temperature. Automatically reset supply temp. by representative building loads or by outside air temp. If boiler design capacity exceeds 300,000Btu/h.
How Water Pumps	30 F temperature drop from 180F to 150F, operating at 60ft of head and a combined impeller and motor efficiency of 60%	The same as proposed design pump power. Pump curve or VSD when pump head exceeding 100ft and motor exceeding 50hp

Table 4.15 Comparison of Number of Chillers between Standard 90.1-1989 and 2001 Model

Total Chiller Plant Capacity		Number of Chiller
1989 Budget Model	2001 Budget Model	
≤ 600 tons	≤.300 tons	1
≥ 600 tons	> 300 tons, < 600 tons	2 sized equally
-	≥600 tons	2 minimum with chillers added so that no chiller is larger than 800 tons, all sized equally

(Note. From Table 13-6 in Standard 90.1-1989 and Table 11.4.3B in Standard 90.1-2001).

Table 4.16 Comparison of Water Chiller Types between Standard 90.1-1989 and 2001 Model

Individual Chiller Plant Capacity		Electric Chiller Type	Remarks
1989 Budget Model	2001 Budget Model		
≤ 175 tons	≤ 100 tons	Reciprocating	
-	>100 tons, < 300 tons	Screw	
≥ 175 tons	≥ 300 tons	Centrifugal	

(Note. Reorganized from the Table 13-6 in Standard 90.1-1989 and the Table 11.4.3C in Standard 90.1-2001).

Figure 4.33 and Figure 4.34 show the flow charts for determining HVAC equipment size, type and number, and efficiency for the 1989 and 2001 budget models used in this study, respectively. The 90.1-1989 and 2001 sizing loops were originally developed for the SB5 web-based simulations with several runs (Ahmad et al. 2005), which were simplified in this study with some modifications for both the 90.1-1989 and 2001 budget model. From the first run with pre-determined system types, HVAC system sizes are calculated automatically by DOE-2 simulation for both the 90.1-1989 and 2001 Budget models. For the 90.1-1989 budget model, equipment type, number, and efficiency were determined after the first run and then finally were run with determined equipment type, number, and efficiency. In the case of the 90.-2001 budget model, one more run was performed to appropriately select equipment efficiency based on the determined equipment number. Table 4.17 shows the minimum equipment efficiency requirements of the Standard 90.1-1989 and 90.1-2001 budget models for the case study building.

Table 4.17 Comparison of Chilling Package- Minimum Requirements between the Standard 90.-1989 and 2001 Models

Equipment type	Size category	Standard 90.1-2001 Minimum efficiency	Standard 90.1-1989 Minimum efficiency	Remarks
Water cooled, electrically operated, centrifugal	< 150 tons	4.45 COP 5.20 IPLV	3.70 COP 3.80 IPLV	
	≥150 tons and <300 tons	4.90 COP 5.60 IPLV	3.70 COP 3.80 IPLV	
	≥300 tons	6.10 COP 6.40 IPLV	4.60 COP 4.70 IPLV	

(Note: Table 10-7 in the Standard 90.1-1989 and Table 6.2.1C in the Standard 90.1-2001).

For the 90.1-1989 and 2001 budget models, a 80% of combustion efficiency is required as a minimum efficiency for the Gas- and Oil-fired boiler above 2,500,000 Btu/h input size as shown in Table 4.18. For Water Heating Equipment, Energy factor(EF) and thermal efficiency (E_t) are minimum requirements, while standard loss(SL) is maximum Btu/h based on a 70 F temperature difference between stored water and ambient requirements. In the EF equation, V is the rated volume in gallons. In the SL equation, V is the rated volume in gallons and Q is the nameplate input rate in Btu/h. For Heat Rejection Equipment, performance requirement is determined by equipment type and flow rate. Table 4.19 compares the performance requirements for the water heating equipment between Standard 90.1-1989 and 2001 models.

Table 4.18 Comparison of Gas- and Oil-Fired Boiler-Minimum Requirements between Standard 90.1-1989 and 2001 Models

Equipment type	Size category (Input)	Subcategory or rating condition	90.1-2001 Minimum efficiency	90.1-1989 Minimum efficiency	Test procedure
Boilers, Gas-Fired	<300,000 Btu/h	Hot water	80% AFUE	80% AFUE (Jan, 1, 1992)	DOE 10 CFR Part 430
		Steam	75% AFUE		
	≥300,000 Btu/h and ≤2,500,000 Btu/h	Maximum Capacity	75% E_t	80% E_C (Jan. 1, 1992)	H.I. Htg Boiler Std.
	>2,500,000 Btu/h	Hot Water	80% E_c		
	>2,500,000 Btu/h	Steam	80% E_c		

(Note: Table 6.2.1F ASHRAE Standard 90.1-2001 and Table 10-8 in the Standard 90.1-1989).

Table 4.19 Comparison of Performance Requirements for Water Heating Equipment between the Standard 90.1-1989 and 2001 Models

Equipment Type	Size category (Input)	Subcategory or rating condition	90.1-2001 Performance Required	90.1-1989 Performance Required	Test procedure
Electric Water Heater	≤ 12 KW	Resistance > 20 gal	0.93-0.00132V EF	0.93-0.0013V EF	DOE 10 CFR Part 430
	> 12 KW	Resistance > 20 gal	20 + 35 √V SL, Btu/h	SL < 4 W/ft^2	ANSI Z21.10.3 (ANSI C72.1-1972)
	≤ 24 Amps and ≤ 250 Volts	Heat Pump	0.93-0.0019 V EF	-	DOE 10 CFR Part 430

(Note: Table 7.8 ASHRAE Standard 90.1-2001 and Table 11-1 in the Standard 90.1-1989).

Table 4.20 summarized the DOE-2 HVAC parameters for Standard 90.1-1989 and 2001 budget model used in this study, including: AHU type, system fan, chillers, cooling tower, boiler, domestic hot water, and pumps.

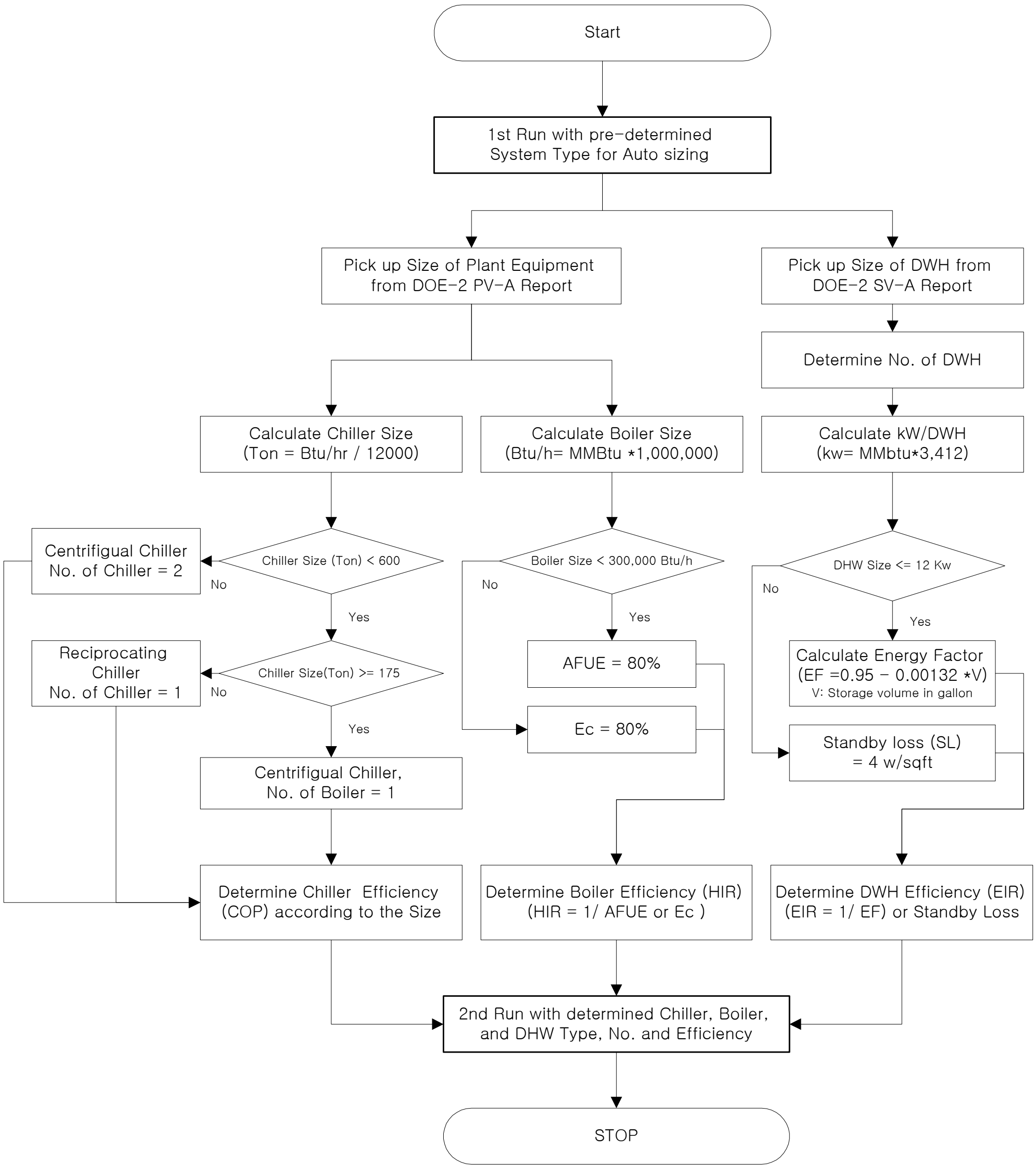


Figure 4.33 *Flow chart for determining the HVAC equipment type, size, and number for the Standard 90.1-1989 budget model.*

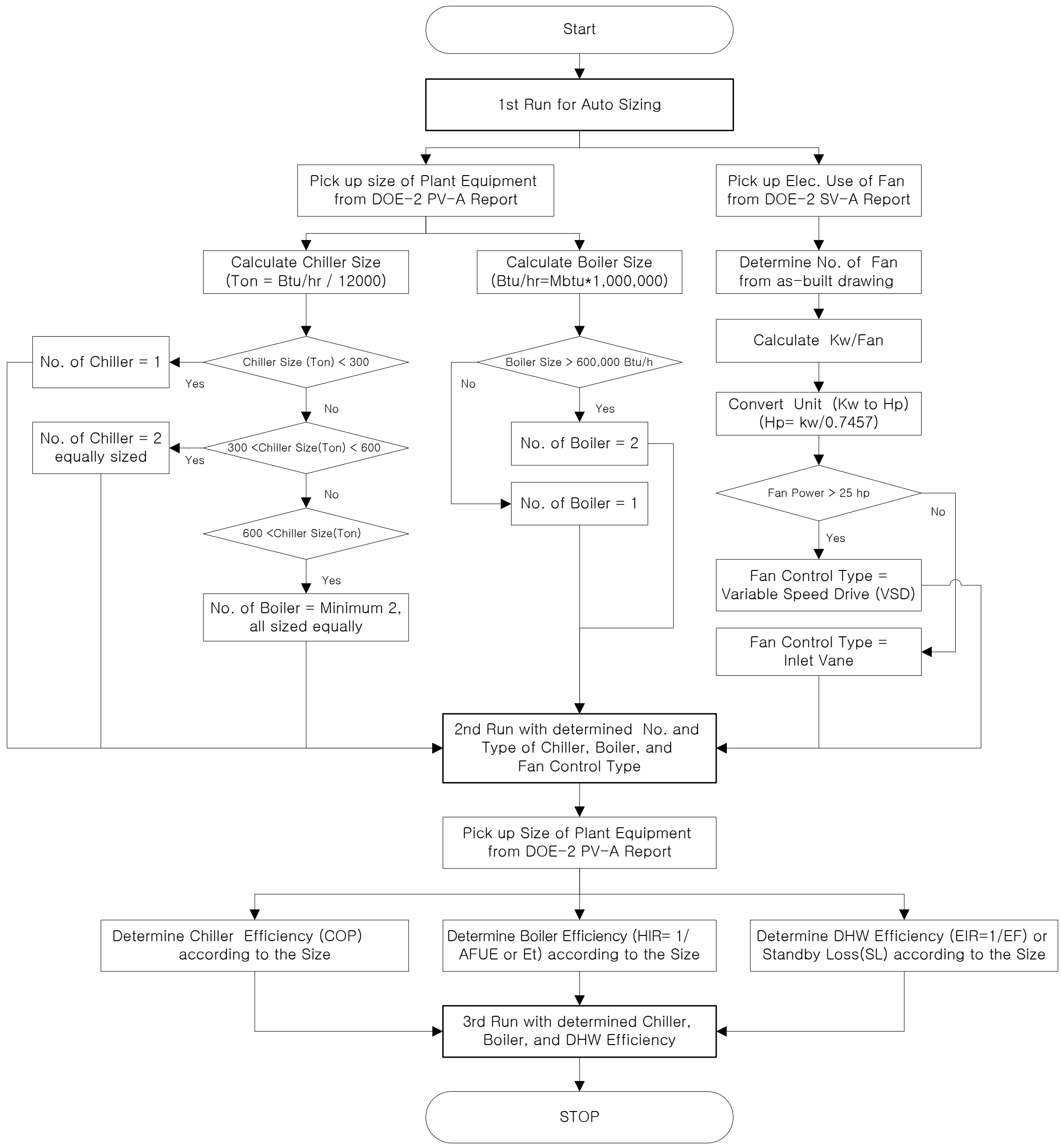


Figure 4.34 *Flow chart for determining the equipment type, size, and number for the Standard 90.1-2001 budget model.*

Table 4.20 Comparison of DOE-2 HVAC Models between the Standard 90.1-1989 and 2001 Models

Measures (DOE-2 Commands)	1989 Budget Model	2001 Budget Model	Proposed Design Model (Calibrated As-built Model)
SYSTEM TYPE	SZRH	DDVAV	DDVAV
SYSTEM FAN			
FAN-CONTROL	VFD	Inlet	VFD
SUPPLY-STATIC	4 inch	4 inch	4 inch
SUPPLY-MECH-EFF	0.55	0.51	0.51
CHILLER			
TYPE	HERM-CENT-CHLR	HERM-CENT-CHLR	HERM-CENT-CHLR
SIZE	Auto Size	Auto Size	5.58 (465 ton)
INSTALL NUMBER	2	2	2 with 1 standby
ELEC-INPUT-RATIO	0.2174 (4.6 COP)	0.1613 (6.2 COP)	0.1547 (6.59 COP)
CHILL-WTR-T	44 F	44 F	44 F (DOE-2 Default)
COMP-TO-TWR-WTR	3	3	3 (1395 gpm / 465 ton)
COOLING TOWER			
TYPE	OPEN-TWR	OPEN-TWR	OPEN-TWR
SIZE	12	12	12 (MMBtu/h) (1000 ton)
TOWER-DESIGN-APPROACH	10 F	10 F	7 F (DOE-2 Default)
TER-SET-T	65 F	70 F	80 F
ELEC-INPUT-RATIO	0.00455	0.00455	0.00455 ((20/3000) * 0.6818)
BOILER			
TYPE	HW-BOILER	HW-BOILER	HW-BOILER
SIZE	Auto Size	Auto Size	4.2
INSTALL NUMBER	2	2	1 with 1 Standby
HW-BOILER-HIR	1.33 (1/Ec =75%)	1.25 (1/Ec =80%)	1.19 (4.98/4.185)
DHW			
TYPE	ELEC-DHW-HEATER	ELEC-DHW-HEATER	ELEC-DHW-HEATER
SIZE	Auto Size	Auto Size	Auto Size
DHW-EIR	1.1695(1/0.855)	1.171(1/0.854)	1 (DOE-2 Default)
PUMP			
CCIRC-PUMP-TYPE	VARIABLE-SPEED	VARIABLE-SPEED	VARIABLE-SPEED
CCIRC-HEAD	75 FT	75 FT	50 FT
CCIRC-DESIGN-T-DROP	12 F	12 F	10 F (DOE-2 Default)
CCIRC-MOTOR-EFF	0.65	0.87	0.9 (DOE-2 Default)
CCIRC-IMPELLER-EFF	0.65	0.87	0.77 (DOE-2 Default)
HCIRC-PUMP-TYPE	VARIABLE-SPEED	VARIABLE-SPEED	VARIABLE-SPEED
HCIRC-HEAD	60 FT	60 FT	35 FT
HCIRC-DESIGN-T-DROP	30 F	30 F	30 F (DOE-2 Default)
HCIRC-MOTOR-EFF	0.6	0.75	0.9 (DOE-2 Default)
HCIRC-IMPELLER-EFF	0.6	0.75	0.77 (DOE-2 Default)

4.4. Energy Metering and In-situ Measurements

This sub-chapter describes energy metering and in-situ measurements as a part of energy performance Measurement and Verification (M&V) of the case study building, including: whole-building energy monitoring, Air Handling Unit (AHU) measurements, low-e glazing measurements, and so on.

4.4.1 Whole-building Energy Monitoring

To accomplish the site measurements, three synergistic data acquisition systems were installed to monitor the data from the sensors installed for measuring whole-building energy use and HVAC&R equipment operation of the case-study building. Figure 4.36 shows the location of data logger #216 in the main electrical room in the basement of the building. Figure 4.38 shows the location of data logger #215 in the 4th floor mechanical room, and the location of logger #217 in the central plant room. Each data logger is shown in Figure 4.37 to Figure 4.39. Table 4.21 shows the data loggers and channel information with various sensors installed in the case-study building. The hourly measured data from each sensor in Table 4.21 are plotted in Appendix D. Chapter V shows comparisons of the daily energy data measured for the years 2001 and 2004. Figure 4.40 provides the monitoring diagram for the three data loggers and metered data points for the case-study building. Data logger #216 includes the Whole-Building Electricity (WBE) use and other independent electricity use. Data logger #215 is connected to the Motor Control Center (MCC) and the thermal energy sensors, such as chilled water flow and temperature. Data logger #217 was installed for monitoring lighting and receptacle electricity use on the 4th floor and solar radiation through the low-e glazing of the south window on the 4th floor. Figure 4.41 shows the detailed monitoring diagram of the central plant, which includes each channel number for data logger #215. Figure 4.42 to Figure 4.49 show pictures taken from the case-study building in relation to the REJ data loggers and sensor locations installed by Energy Systems Laboratory.

Table 4.21 REJ Data Loggers and Channels Information

Logger #	Channel Type	Chan	Description	Chid	Sensors Type	Remarks
Data acquisition system		Synergistic control system C180E DAS with Modem & PT				MAIN CENTRAL PLANT ROOM
215 (2546)	Watt	CT0	MCC Electric	4476	Current Transformer	
		CT1	MCC Electric	4477	Current Transformer	
		CT2	Chiller 1 Elec	4478	Current Transformer	
		CT3	Chiller 1 Elec	4479	Current Transformer	
		CT4	Chiller 2 Elec	4480	Current Transformer	
		CT5	Chiller 2 Elec	4481	Current Transformer	
		CT6	Chiller 4 Elec	4482	Current Transformer	
		CT7	Chiller 4 Elec	4483	Current Transformer	
	Analog	A0	Chil 1 ChWS Flow	4484	Flow Meter	ONICON FM 0-1200 GPM
		A1	Chil 1 ChWS Temp	4485	RTD Temp	1000 OHM RTD
		A2	Chil 1 ChWR Temp	4486	RTD Temp	1000 OHM RTD
		A3	Cond 1 Sup Temp	4487	RTD Temp	1000 OHM RTD
		A4	Cond 1 Ret Temp	4488	RTD Temp	1000 OHM RTD
		A5	Chil 2 ChWS Flow	4489	Flow meter	ONICON FM 0-1200 GPM
		A6	Chil 2 ChWS Temp	4490	RTD Temp	1000 OHM RTD
		A7	Chil 2 ChWR Temp	4491	RTD Temp	1000 OHM RTD
		A8	Cond 2 Sup Temp	4492	RTD Temp	1000 OHM RTD
		A9	Cond 2 Ret Temp	4493	RTD Temp	1000 OHM RTD
		A10	HW Flow	4494	Flow meter	ONICON FM 0-400 GPM
		A11	HW Sup temp	4495	RTD Temp	1000 OHM RTD
		A12	HW Ret temp	4496	RTD Temp	1001 OHM RTD
User Channel		-	Chiller 1 kBtu	4520	kBtu = (gph * (supply T - return T))/2	
User Channel		-	Chiller 2 kBtu	4521	kBtu = (gph * (supply T - return T))/2	
User Channel		-	HW kBtu	1522	kBtu = (gph * (supply T - return T))/2	
Data acquisition system		Synergistic control system C160E DAS with Modem & PT				MAIN ELEC. ROOM-LOWER LEVEL
216 (2900)	Watt	CT0	Bldg Electric 1	4497	Current Transformer	
		CT1	Bldg Electric 1	4498	Current Transformer	
		CT2	Bldg Electric 1	4499	Current Transformer	
		CT3	Bldg Electric 2	4500	Current Transformer	
		CT4	Bldg Electric 2	4501	Current Transformer	
		CT5	Bldg Electric 2	4502	Current Transformer	
	Digital	D0	Conf Center Elec	4503	Current Transformer	CH IQ200 METER
		D1	Senate Print shp	4504	Current Transformer	CH IQ200 METER
		D2	TLC Print Shop	4505	Current Transformer	CH IQ200 METER
Data acquisition system		Synergistic control system C140E DAS with Modem & PT				4TH FLOOR TELECOMM ROOM
217 (2901)	Watt	CT0	4th Floor East	4506	Current Transformer	
		CT1	4th Floor East	4507	Current Transformer	
		CT2	4th Floor East	4508	Current Transformer	
		CT3	4th Floor Central	4509	Current Transformer	
		CT4	4th Floor Central	4510	Current Transformer	
		CT5	4th Floor Central	4511	Current Transformer	
		CT6	4th Floor West	4512	Current Transformer	
		CT7	4th Floor West	4513	Current Transformer	
		CT8	4th Floor West	4514	Current Transformer	
		CT9	Summed XFMRS	4515	Current Transformer	
		CT10	Summed XFMRS	4516	Current Transformer	
		CT11	Summed XFMRS	4517	Current Transformer	
	Analog	A0	Solar -West	4518	Solar Radiation	Conference room 4.411 on 4th floor
		A1	Solar -South	4519	Solar Radiation	Conference room 4.411 on 4th floor

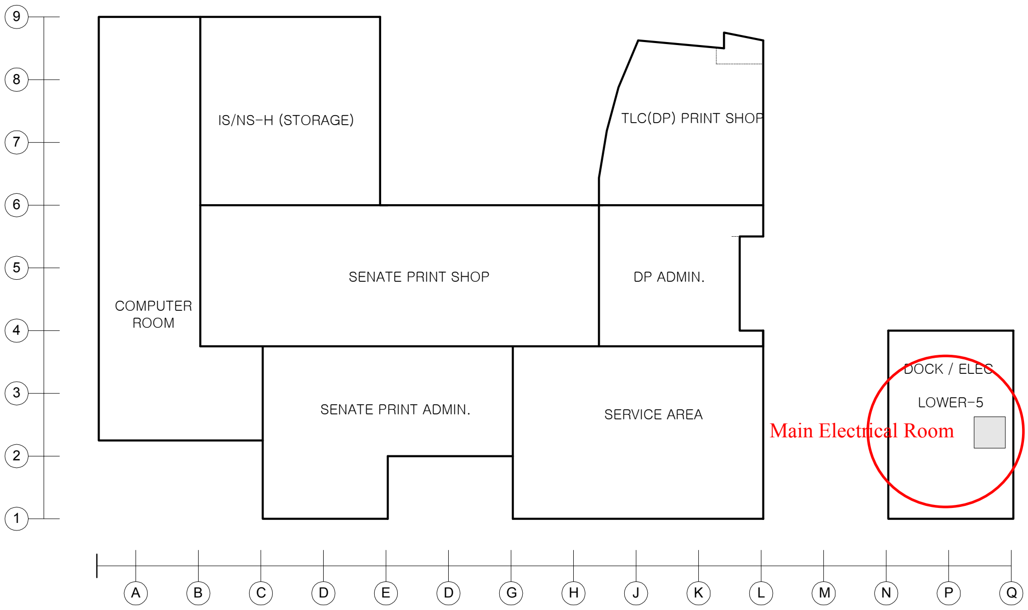


Figure 4.35 *Location of the data logger #216 in the main electrical room in the basement.*

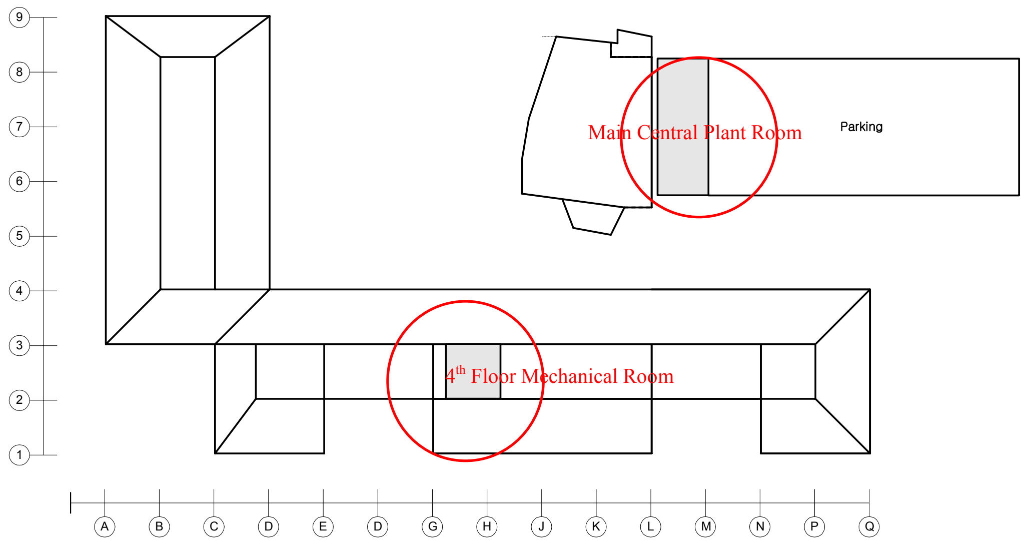


Figure 4.36 *Location of data logger #215 in the central plant room and data logger #217 in the 4*th *floor mechanical room.*

Figure 4.37 *Synergistic data logger #216.*

Figure 4.38 *Synergistic data logger #215.*

Figure 4.39 *Synergistic data logger #217.*

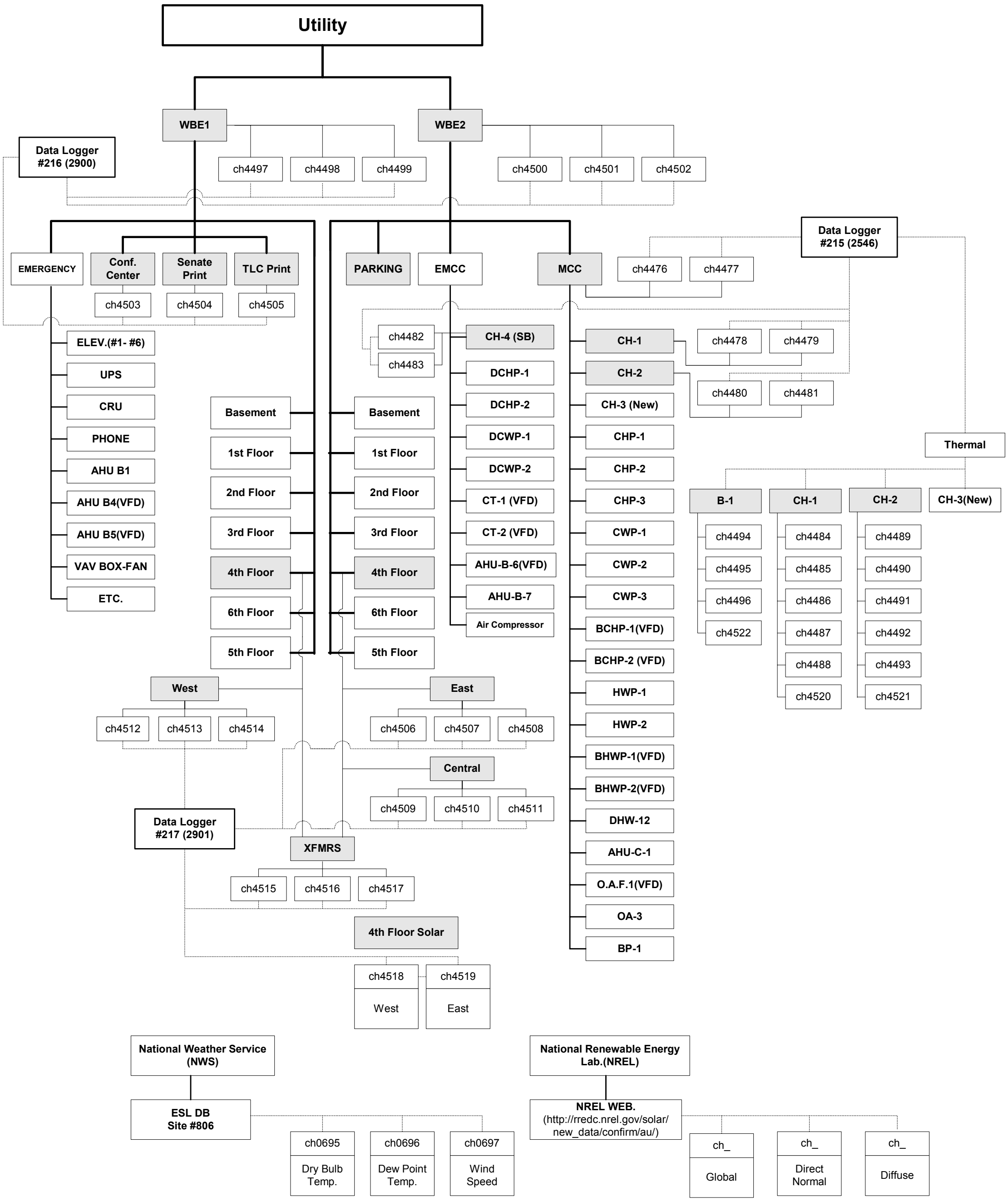


Figure 4.40 *Whole–building monitoring diagrams of the REJ building.*

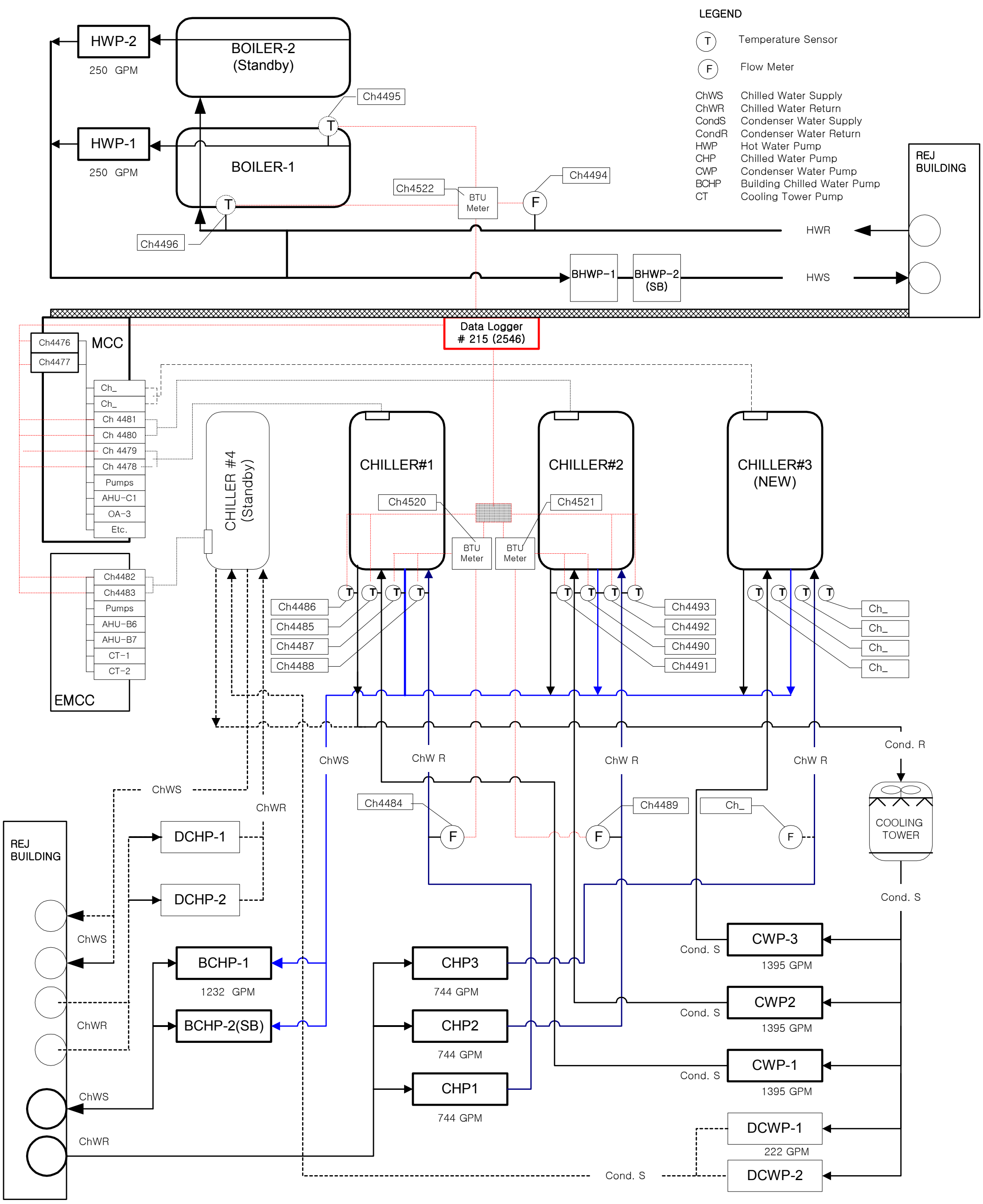


Figure 4.41 *Central plant monitoring diagram of the REJ building.*

Figure 4.42 *Main electrical room with data logger #216 and WBE panel.*

Figure 4.43 *WBE panel #1 in the main electrical room.*

Figure 4.44 *MCC panel #1 in the central plant room.*

Figure 4.45 *MCC panel with the CT#1 and CT#2 for chiller #2.*

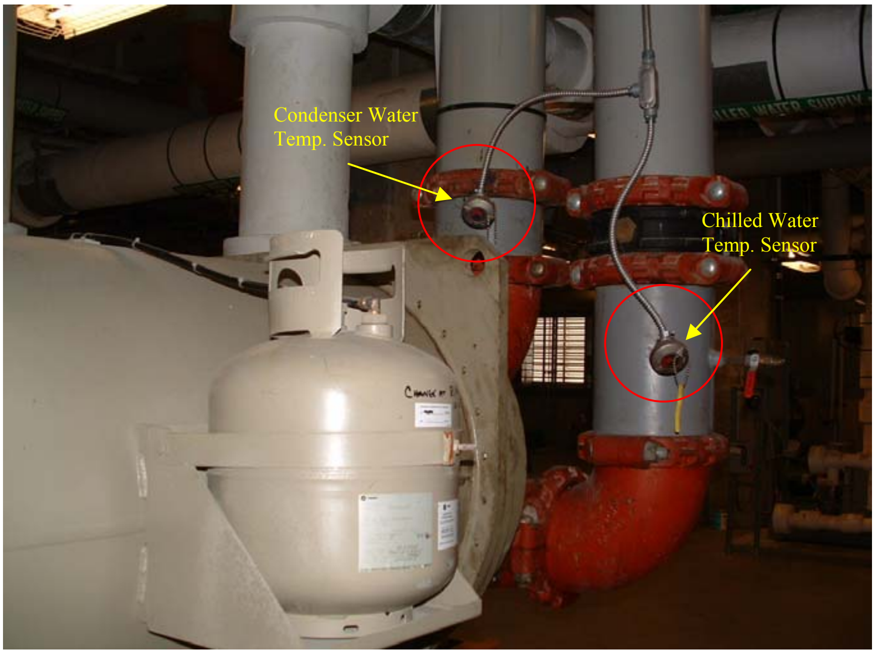


Figure 4.46 *Condenser water temperature sensor for chiller #1..*

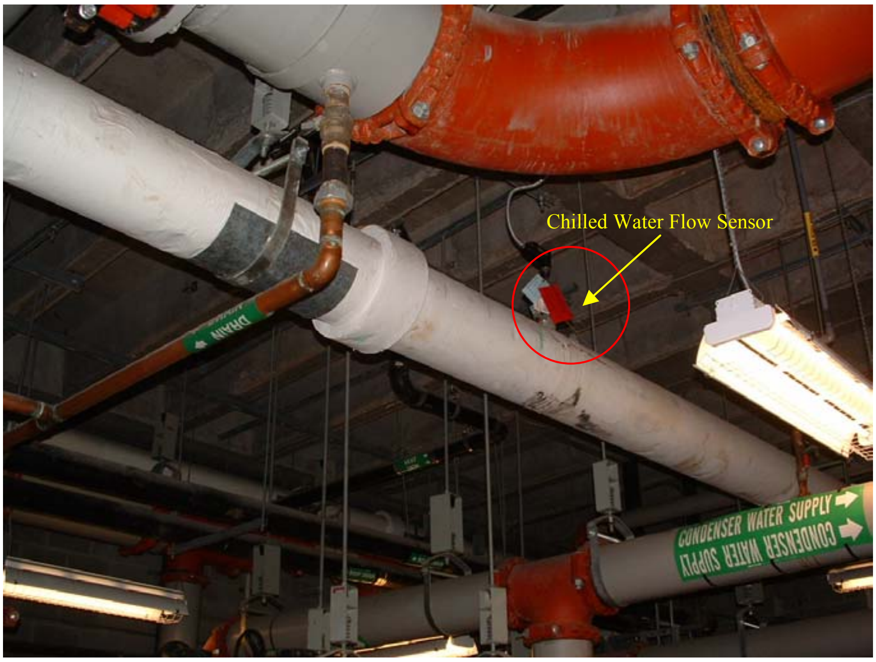


Figure 4.47 *Chilled water flow sensor for chiller #1.*

Figure 4.48 *New chiller without sensors.*

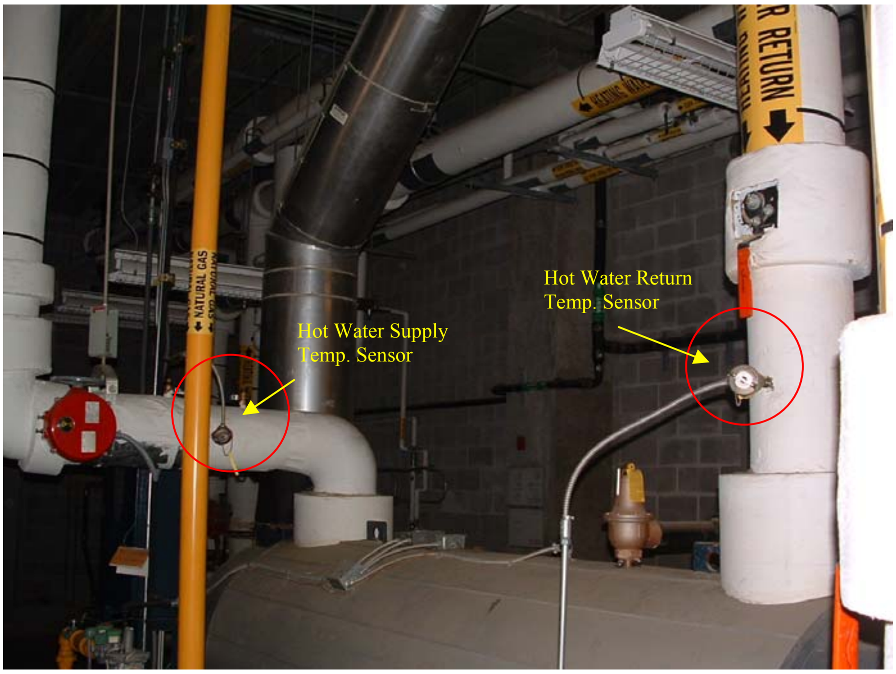


Figure 4.49 *Hot water supply and return temperature sensor for boiler #1..*

4.4.2 Air Handling Unit (AHU) Measurements

One AHU and its related zones on the 4th floor of the case-study building were selected for additional measurements. On-site measurements were performed to verify the operational temperature and relative humidity using portable data loggers for short-term periods. This Section describes the sensor calibration and installation of the portable data loggers used in this portion of the study.

4.4.2.1 Temperature and RH Sensor Calibration

The portable temperature and RH Sensors used in this study were calibrated based on American Society of Testing and Materials (ASTM) standard practice (ASTM 1996,1997,1998) and the national Bureau of Standard (NBS) Monograph 174 and 150 (Wise and Soulen 1986). Figure 4.50 shows the calibration flowchart of the temperature and RH sensors used in this study. Two platinum RTD sensors were first calibrated based on the average readings of the primary and secondary ASTM thermometers at ice-point 32 F (Wise and Soulen 1986). Figure 4.51 shows the thermally insulated ice-point bath (ASTM 1997), which includes three reference thermometers and the two RTD sensors connected to the data logger. Table 4.22 shows the operation range and accuracy of the reference devices for the calibration of the temperature sensors used in this study. Table 4.23 summarizes the measured results and scale corrections for the calibration of the two RTD sensors.

Table 4.22 Operation Range and Accuracy of Reference Temperature Devices

Instruments	Operating range	Accuracy	Remarks
Two ASTM 63F thermometers -108 mm immersion	18 F to 89 F	0.2 Division	As primary standard device at ice-point temp. (32F)
A Precision thermometer - 76 mm immersion	30F to 214F	0.5 Division	As check of the standard device
Two 1000 Ohm Platinum RTD Sensors	- 40F to 500F	± 0.1% of span (30F to 320F)	As reference device at wide temp. range

Table 4.23 Temperature Measurements with Scale Correction at Ice-point (32F)

Readings	Uncorrected (F)		Primary (F)		Check(F)	Scale Correction (F)	
	RTD1	RTD2	ASTM 1	ASTM 2	Lab. 1	RTD 1	RTD 2
First	30.30	30.30	32.00	32.00	32.00	1.70	1.70
Second	30.30	30.30	32.00	32.00	32.00	1.70	1.70

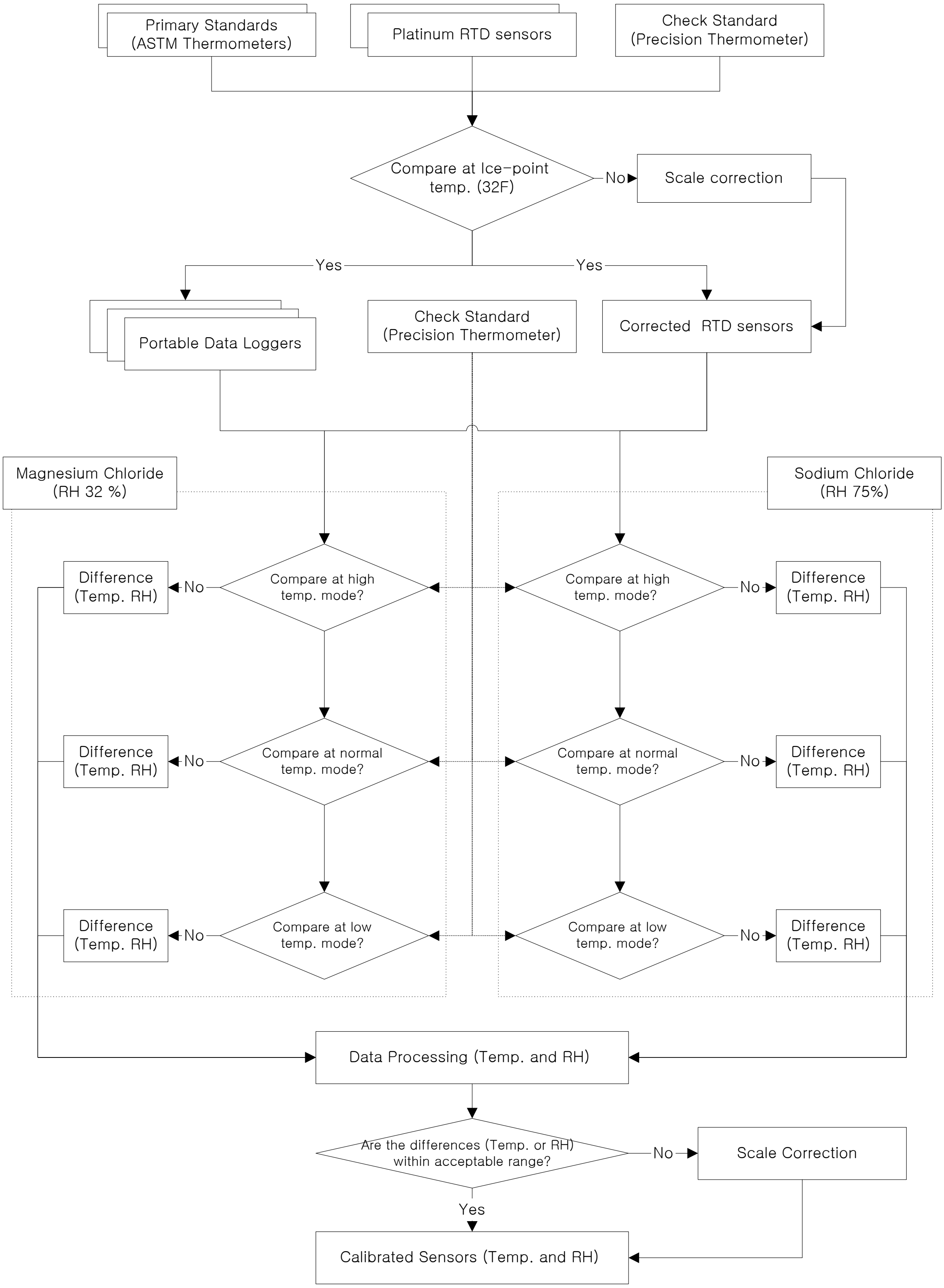


Figure 4.50 *Flowchart of temperature and RH sensor calibration.*

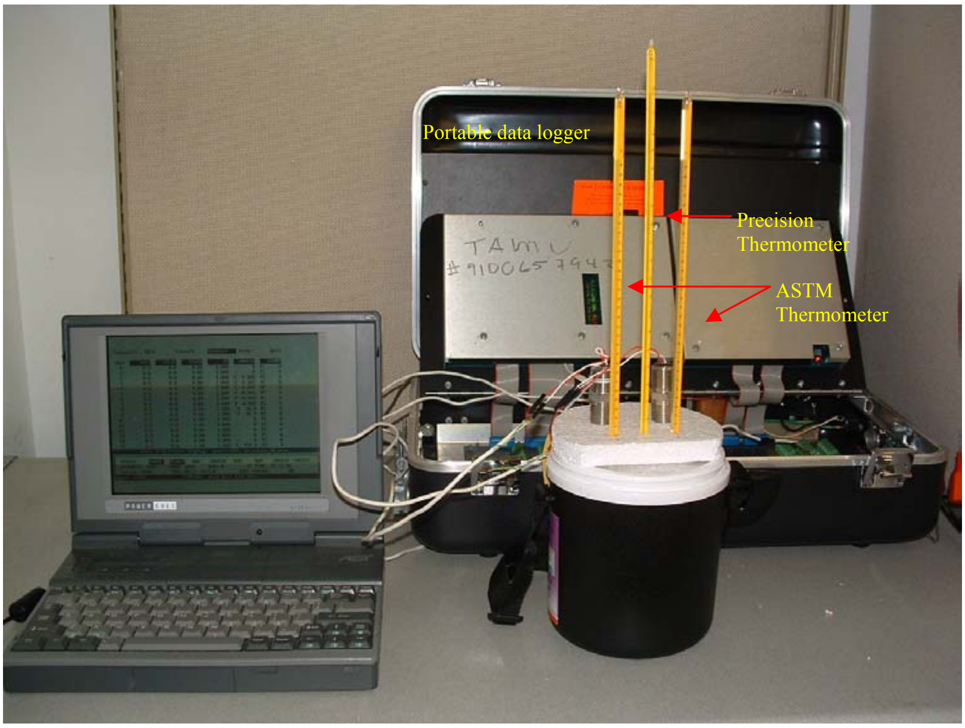


Figure 4.51 *An ice-point bath with thermometers and two RTD sensors connected to a data logger.*

The temperature and relative humidity of the portable data loggers were measured at three temperatures in selected aqueous, saturated salt solutions such as magnesium chloride (RH 32%) and sodium chloride (RH 75%) (ASTM 1996). The calibration points were set at high (about 104 F), normal (about 86F), and a low (44F) temperature. Table 4.24 shows the measurement results and the accuracy provided by the manufacturer. Most measured data in the experiments were verified within acceptable ranges provided by the manufacturer so that no correction was performed for the portable data loggers used in this study. Appendix E.1 shows the detailed calibration procedure and graphical results for each experiment. In this experiment, a small fan in the refrigerator allowed the air to fully circulate to minimize any temperature variations as shown in Figure 4.52.

Table 4.24 Comparison of the Sensor Accuracy between Measured and Manufacturer Data.

Source	Temperature (F)		Relative Humidity (%)		Remarks
	Operating Range	Accuracy	Operating Range	Accuracy	
Manufacturer	- 4 – 158 F	± 1 F	25 – 95%	± 5%	Onset
Experiments	97.15 - 104.95	0.00 - 1.78	Magnesium Chloride (32)%	3.13 – 5.03	Hot Mode
	85.70 – 87.07	0.52 - 1.28		1.87 – 3.17	Normal Mode
	43.06 – 43.59	0.12 - 0.86		0.15 - 0.75	Cold Mode
	103.88-106.75	1.96 – 4.55	Sodium Chloride (75)%	8.17-12.42	Hot Mode
	85.07-86.31	0.48 – 2.00		4.23 - 7.81	Normal Mode
	53.68-54.02	0.08 - 0.90		0.09 - 2.61	Cold Mode

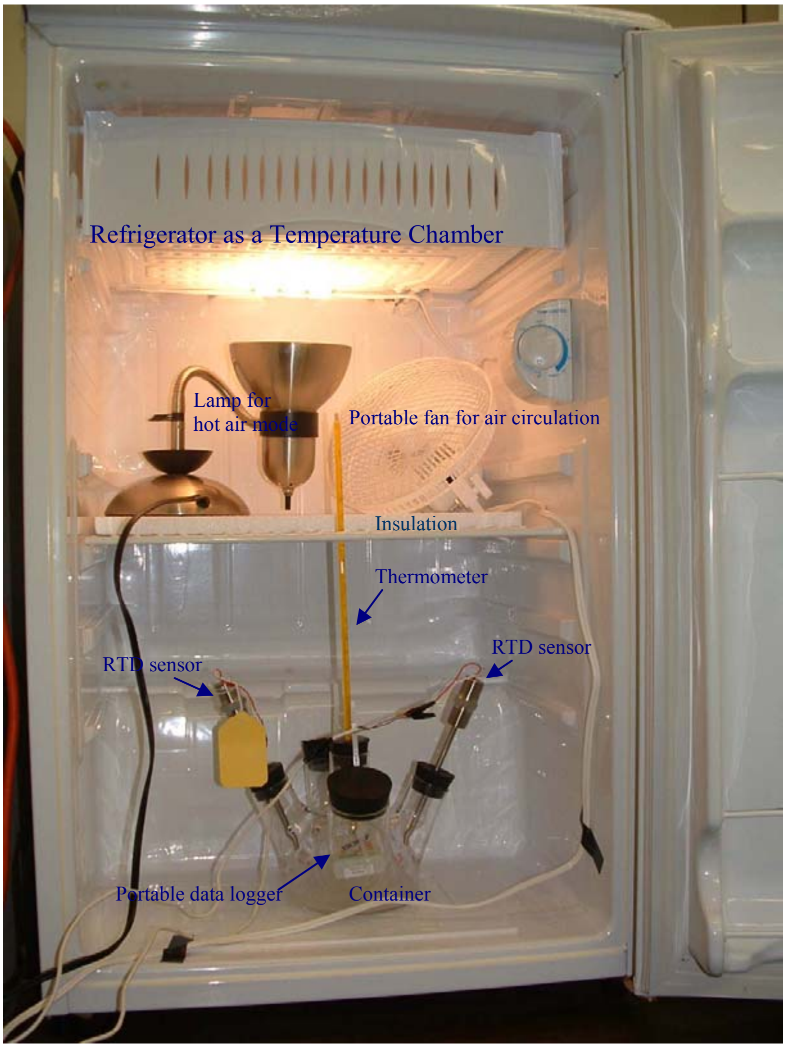


Figure 4.52 *A refrigerator as a temperature and humidity chamber with a container including two portable data loggers, two RTD sensors, and a check standard thermometer.*

4.4.2.2 Installation of the Portable Data Loggers

Eight portable data loggers were installed to verify actual operation (e.g., temperature and relative humidity) of the selected AHU (DDVAV) and related spaces on the 4th floor of the case study building, including: (1) Supply ducts and return grills in the south and north zones of the 4th floor, (2) East AHU on the 4th floor (Hot, Cold, and Mixing air room), and (3) OA intake on the roof.

4.4.2.2.1 Indoor Temperature and Relative Humidity

Four portable data loggers were installed to measure indoor temperature and relative humidity at supply ducts and return grills on the south and north zone served from the east AHU of the 4th floor as shown in Figure 4.53. Figure 4.54 to Figure 4.57 are pictures showing installed sensor locations.

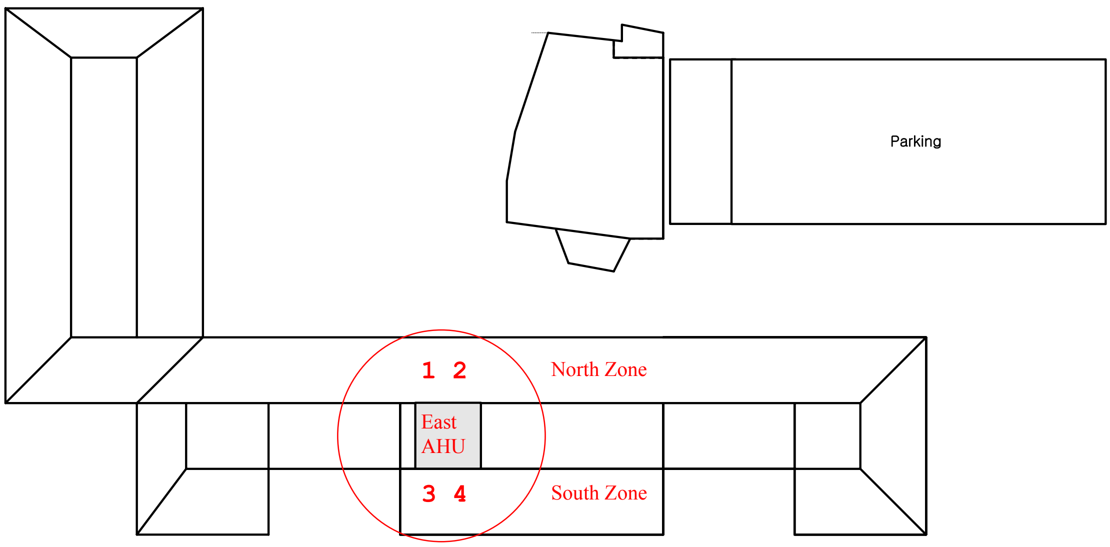


Figure 4.53 *South and north zones served the east AHU on the 4th floor (supply and return).*

Figure 4.54 *North zone return grill (Note: sensor placed above grill).*

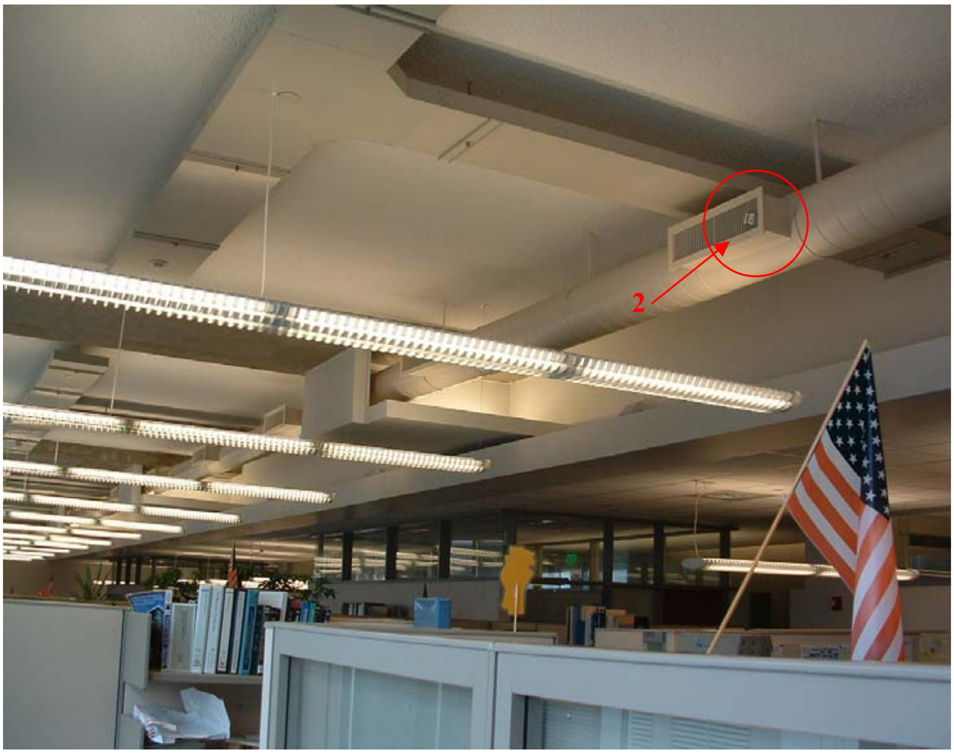


Figure 4.55 *North zone supply duct.*

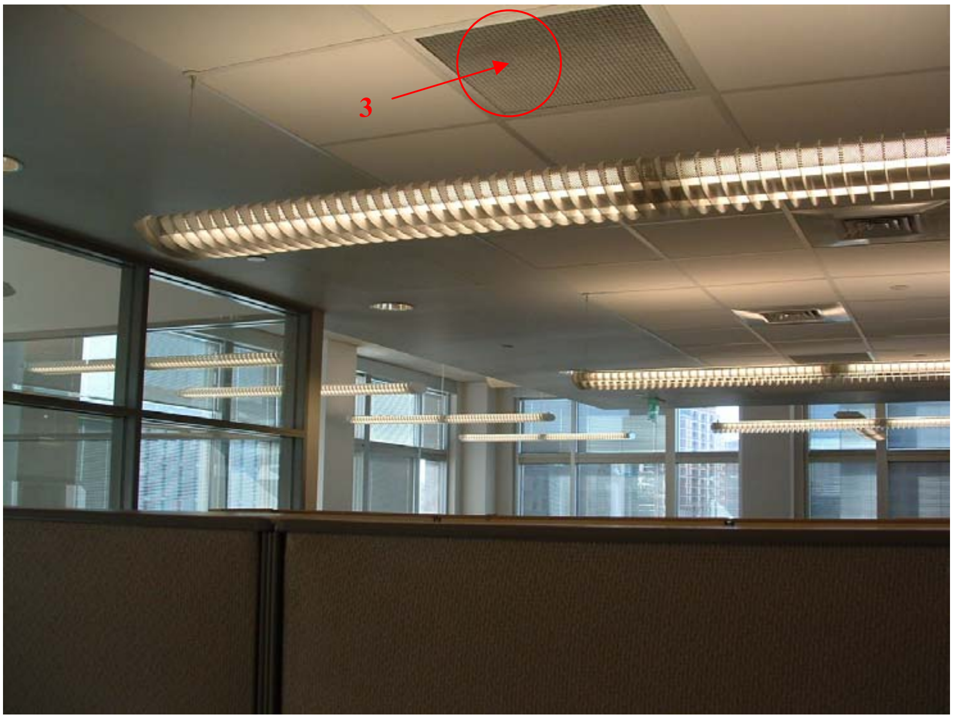


Figure 4.56 *South zone return grill (Note: sensor placed above grill).*

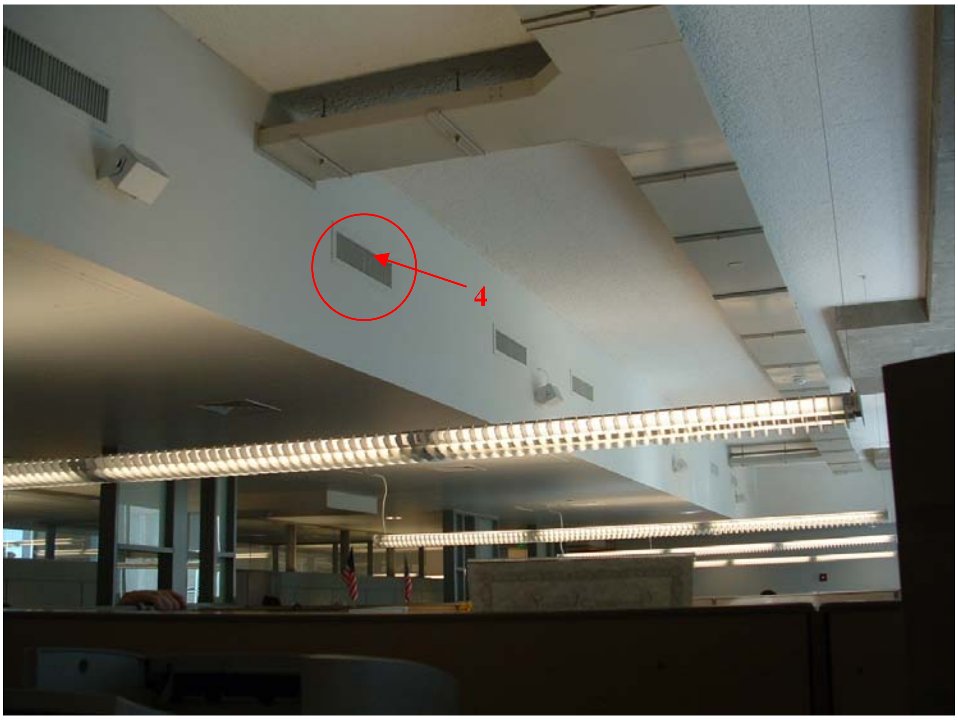


Figure 4.57 *South zone supply duct.*

4.4.2.2.2 East AHU (DDVAV) on the 4th Floor of the REJ building.

Hot deck, cold deck, and mixed air temperature were measured for the east AHU (DDVAV) as shown in Figure 4.58. Outside air temperature and RH were also measured at the air intake on the roof of the case-study building. Figure 4.59 to Figure 4.61 show the locations of the portable data loggers installed in each measurement point related to the east AHU.

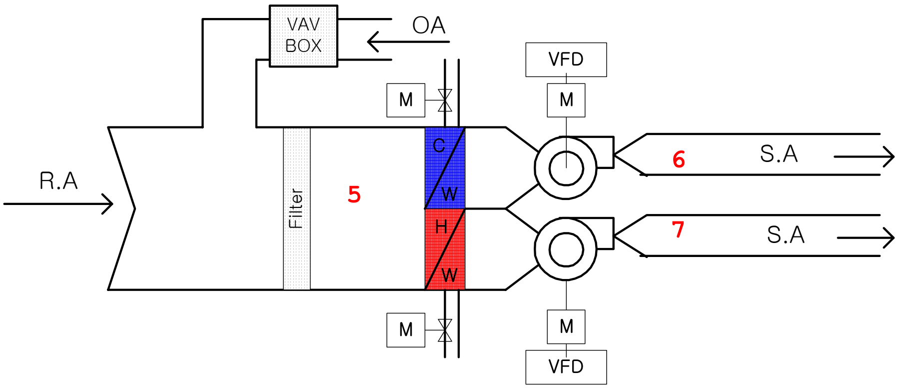


Figure 4.58 *Actual dual-duct VAV system.*

Figure 4.59 *Inside air filters for entering mixing air.*

Figure 4.60 *Hot deck and cold deck door (Note: sensor placed inside the door).*

Figure 4.61 *Outside air intake.*

4.4.3 Low-e Glazing Measurements

As one of the measurement and verification processes in this research, the solar transmittance of the four glazing samples obtained from the manufacturer was measured on selected clear days and compared to that of the window library generated by the Window 5.2 program (LBNL 2004), which is incorporated into the DOE-2 simulation for the case-study building that includes two types of low-e glazing. Table 4.25 shows brief information on the glazing tested in this experiment, including: single-pane clear, double-pane clear, and two types of low-e glazing.

Table 4.25 Test Glazing Information

	General		REJ Building	
Manufacture	AFGD		AFGD	
Type	Clear		Low-E	
Panes	Single	Double	Double	Double
Sample Thickness	1/8”	1/2”	1”	1”
Layer (Outside to Inside)	1/8”clear	1/8”clear +1/4” air +1/8” clear	1/4”low-e +1/2” air +1/4” clear	
Glazing No.	Clear_3DAT	Clear_3DAT	VE1-40#2	VE1-2M
Measurement Date	9/27/05	9/25/05	9/5/05	8/21/05

This Section describes the experimental setup to measure the solar transmittance of the sample glazing, including: (1) calculation of solar transmittance, (2) solar test bench description, and (3) solar sensor (e.g., PSP and Li-Cor pyranometer) calibration. The measurement results from this experiment are discussed in Chapter V, Section 5.5.

4.4.3.1 Calculation of Solar Transmittance

In this study, the total solar transmittance was calculated based on the ratio of the total global horizontal solar radiation measured with and without sample glazing on selected clear days. The solar transmittance is dependent on the angle of incidence as a function of hour angle, which is influenced by local solar time. The local solar time can be obtained from the local correction and equation of time.

$$\text{Local Solar Time (Lst)} = \text{Central Standard Time (CST)} \pm 4\,(\text{Lst} - \text{Loc}) + E \qquad (4.2)$$

Where Lst is the standard meridian for the time zone (Central time zone = 90), Loc is the longitude of the location (Site longitude = 96.3), and E is the Equation of Time (EOT), which is calculated using the equation by Duffie and Beckman (1991).

$$E = 229.2\begin{bmatrix} 0.000075 + 0.001868\cos(\beta) - 0.032077\sin(\beta) \\ -0.014615\cos(2\beta - 0.04089\sin(2\beta) \end{bmatrix} \tag{4. 3}$$

Where the angle β is a function of the day of the year; β = ((n-1) 360/365))

The angle of incidence is calculated every 15 minutes for the selected clear days using equations from Duffie and Beckman (1991).

$$\theta = \cos^{-1}\begin{bmatrix} (\sin\delta\sin\phi\cos\beta) - (\sin\delta\cos\phi\sin\beta\cos\gamma) + (\cos\delta\cos\phi\cos\beta\cos\omega) \\ +(\cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega) + (\cos\delta\sin\beta\sin\gamma\sin\omega) \end{bmatrix} \tag{4.4}$$

Where, ω = Hour angle ((Solar time -12) * 15)
δ = Solar declination (23.45 sin (360(284+n)/365))
ϕ = Latitude
β = Slope
γ = solar azimuth angle

4.4.3.2 Solar Test Bench Description

Figure 4.62 shows the Solar test bench (STB) located on the roof of the Langford Architecture Center at Texas A&M University, which includes the test box containing two types of solar sensors as shown in Figure 4.63. A pyranometer is an instrument for measuring global solar radiation. A Li-Cor pyranometer and two Eppley Precision Spectral Pyranometers (PSPs) were used to measure solar radiation (Munger 1997; Sylvester 1999; Oh 2000; and Klima 2000). Figure 4.64 shows the transmitter box connected to each sensor in the Solar Test Bench. A synergistic data logger in Figure 4.65 was used to collect every 15 minutes for the experiment.

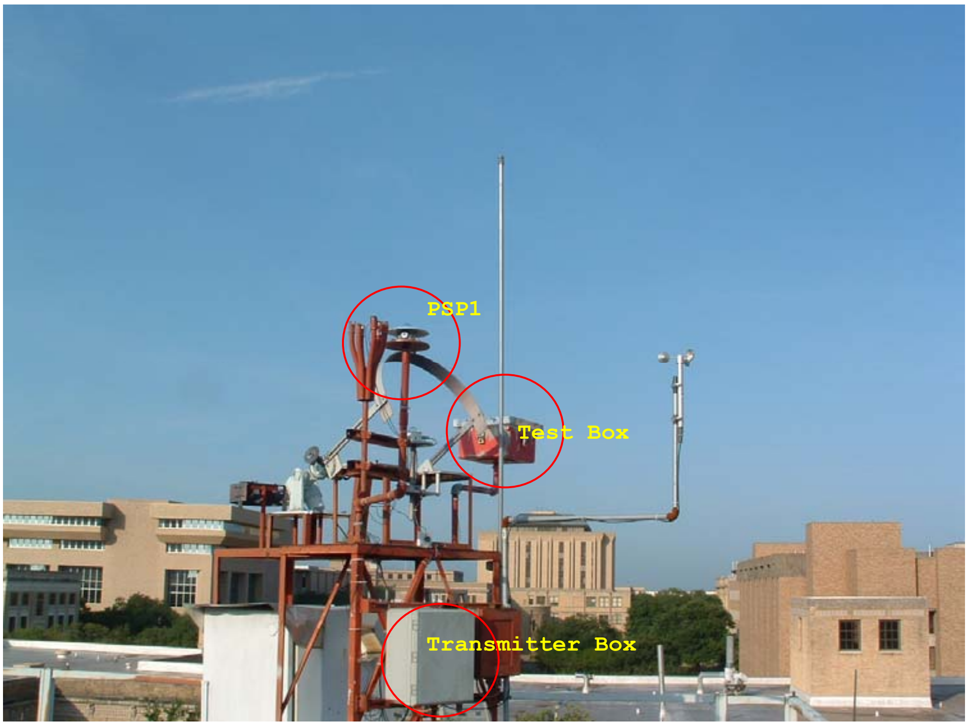


Figure 4.62 *Solar test bench including PSP w/o test box with glazing.*

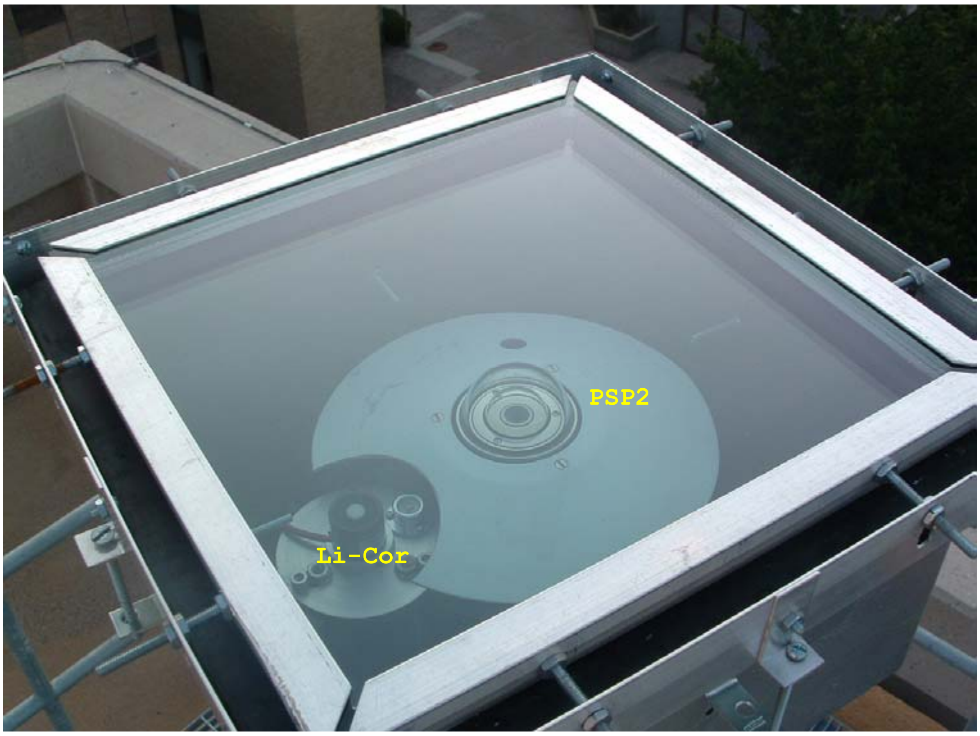


Figure 4.63 *Test box with Eppley PSP and Li-Cor sensor under low-e glazing.*

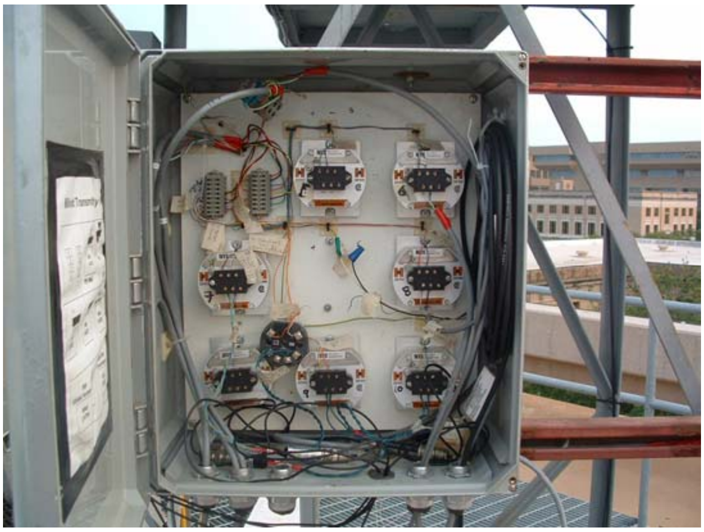


Figure 4.64 *4-20 mA transmitter box for the solar test bench.*

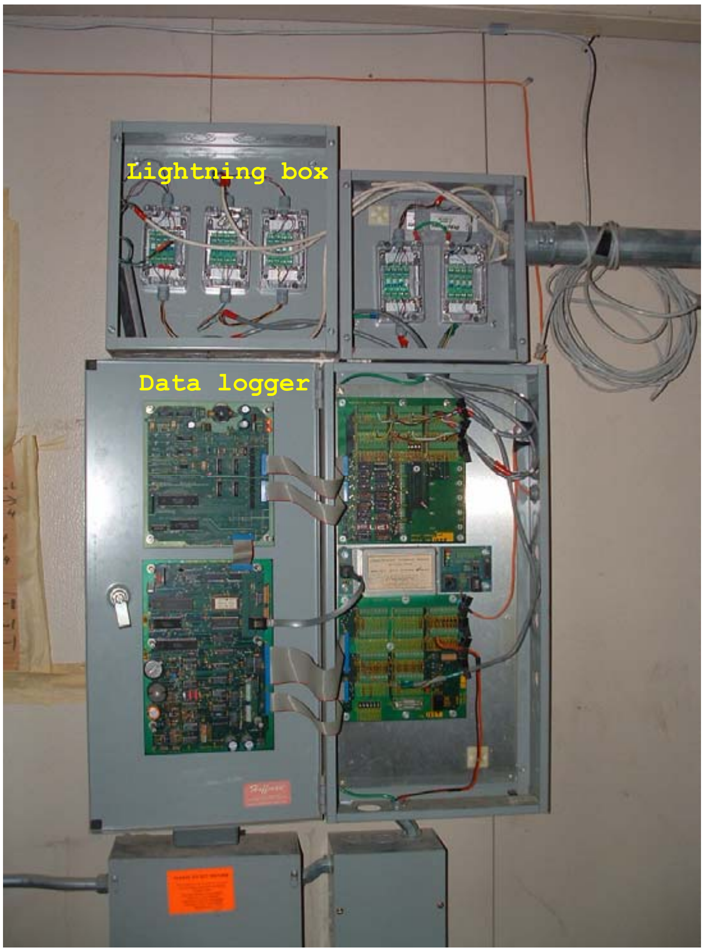


Figure 4.65 *Data logger for the solar test bench.*

4.4.3.3 Solar Sensor Calibration

Solar transmittance of sample glazing was measured in this study using two types of pyranometers such as an Eppley Precision Spectral Pyranometer (PSP) and a Li-Cor pyranometer. Table 4.26 shows the specifications for the Eppley PSP and the Li-Cor in terms of sensor accuracy and spectral response. In general, Li-Cor pyranometers are calibrated against an Eppley Precision Spectral Pyranometer (PSP) under daylight conditions, with a typical error of ± 5% (LI-COR 1991).

Table 4.26 Specification of Epply PSP and Li-Cor

Items	Eppley PSP	Li-Cor (Li-200SA)
Detector Type	Thermopile	Silicon photovoltaic
Temperature dependence	± 1% over range from -20 ^oC to 40 ^oC	0.15% per ^oC
Spectral response	0.285 to 2.8 μ	0.4 to 1.1μ
Sensitivity	Approx. 9 $\mu V/Wm^{-2}$	Approx. 90 $\mu A/1000W/m^{-2}$
Cosine Response	± 1% over range from 0 to 70 ^{O} ± 3% over range from 70 to 80 ^{O}	Corrected up to an 80 ^{O} angle of incidence
Linearity	± 0.5% from 0 to 2800 Wm^{-2}	Maximum deviation of 1% up to 3000 W/m^{-2}
Orientation	No error from orientation or tilt	No error from orientation

The Eppley PSP and the Li-Cor were used in this experiment after instrument correction, scale correction, and site specific correction. Appendix E.2 describes the detailed calibration processes and results for each step. Figure 4.66 is a flow chart that shows the overall calibration process for the Epply PSP and the Li-Cor Sensors used in this study. Prior to the measurement of the solar transmittance through the sample glazing, the two Eppley PSPs used in this study were compared to the calibrated Eppley PSPs from National Renewable Energy Laboratory (NREL), resulting in two regression coefficient that used to correct each sensor based on the comparison between the logger output (V) from the test PSP and the solar radiation (W/m^2) from the NREL PSP. For the sensor calibration in this experiment, an instrument scale correction was first performed for the PSPs and the Li-Cor from the transmitter to the data logger. The photovoltaic-type Li-Cor sensor used in this study also used the scale correction factor provided by manufacturer. Finally, post corrections were also performed after the experiment as shown in Figure 4.66.

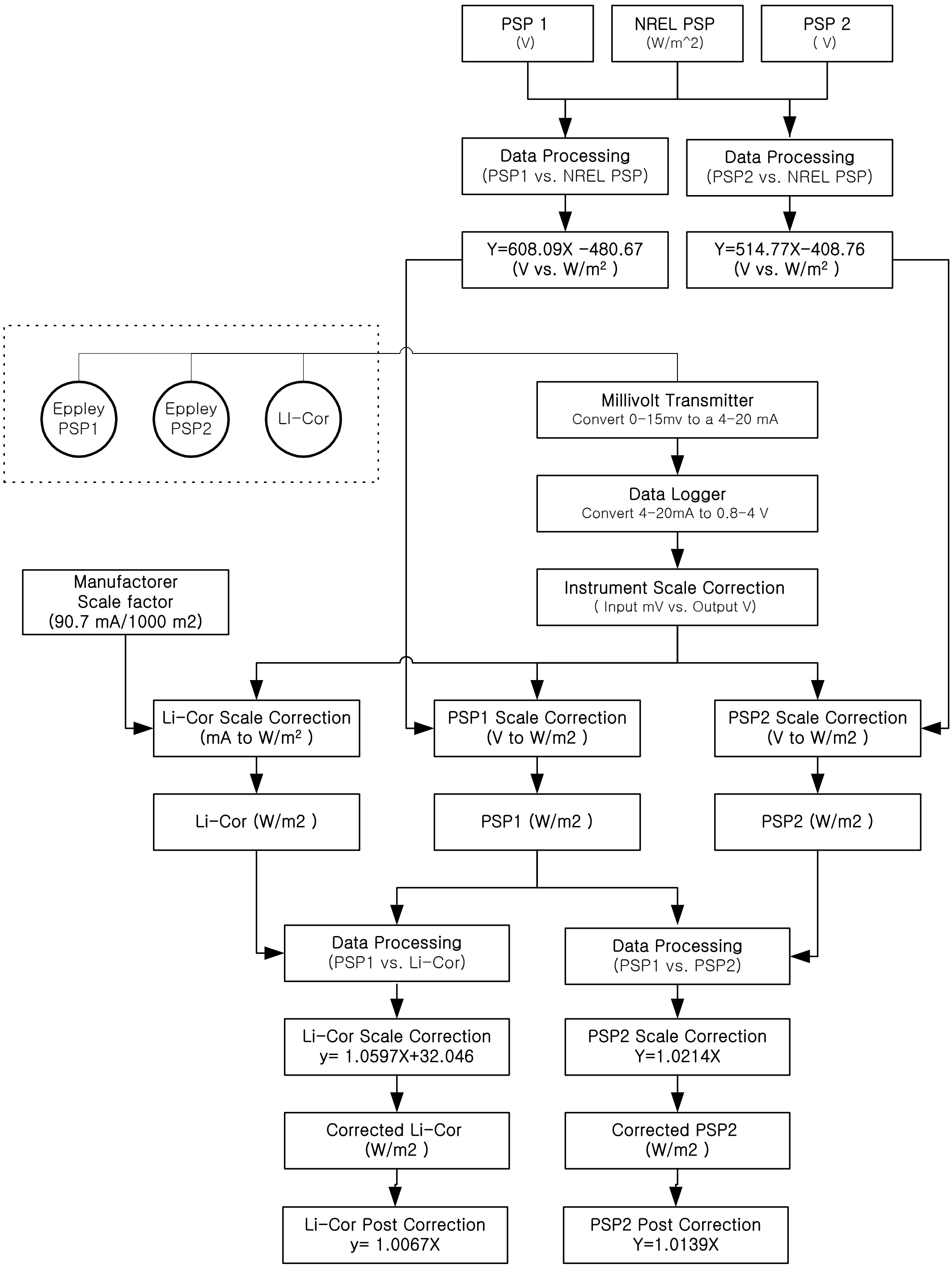


Figure 4.66 *Calibration procedure of the Eppley PSP and Li-Cor sensors used in this study.*

4.5 As-Built Simulation and Calibration

This Section discusses the calibration procedure and methods used in this study, including: (1) As-built simulation and calibration procedure, (2) Weather data packed into TRY format with solar radiation, (3) Typical load day-typing, (4) Low-e window performance, (5) HVAC equipment performance, and (6) Graphical and statistical analysis.

4.5.1 As-built Simulation and Calibration Procedure

Figure 4.67 shows the calibration procedure for the as-built simulation. In the upper left portion of the Figure 4.67, information from site visits, DOE-2 manual, as-built drawings, and measured energy data were used to create a DOE-2 input file. Measured weather data were packed into TRY format, which is described in the following Section 4.5.2. In the upper right portion of Figure 4.67, solar transmittance through sample glazing was measured, compared to that of Window 5.2, and then incorporated into the DOE-2 window library. Section 4.5.5 describes how to generate the DOE-2 window file from Window 5.2 and incorporate it into the DOE-2 window library, which was verified from the DOE-2 hourly report after running the as-built simulation as discussed in Chapter VI, Section 6.2. Once the as-built simulation was performed, the hourly simulated data were extracted from selected DOE-2 reports and then evaluated with graphical and statistical comparison to measured data. The as-built simulation was run again until the simulated data match with measured data to a suitable level, by adjusting calibration factors as shown in the lower left portion of the Figure, in terms of building loads, systems, and plants. Calibration procedures with major factors for the as-built simulation model are discussed in detail in Chapter VI, Section 6.2.

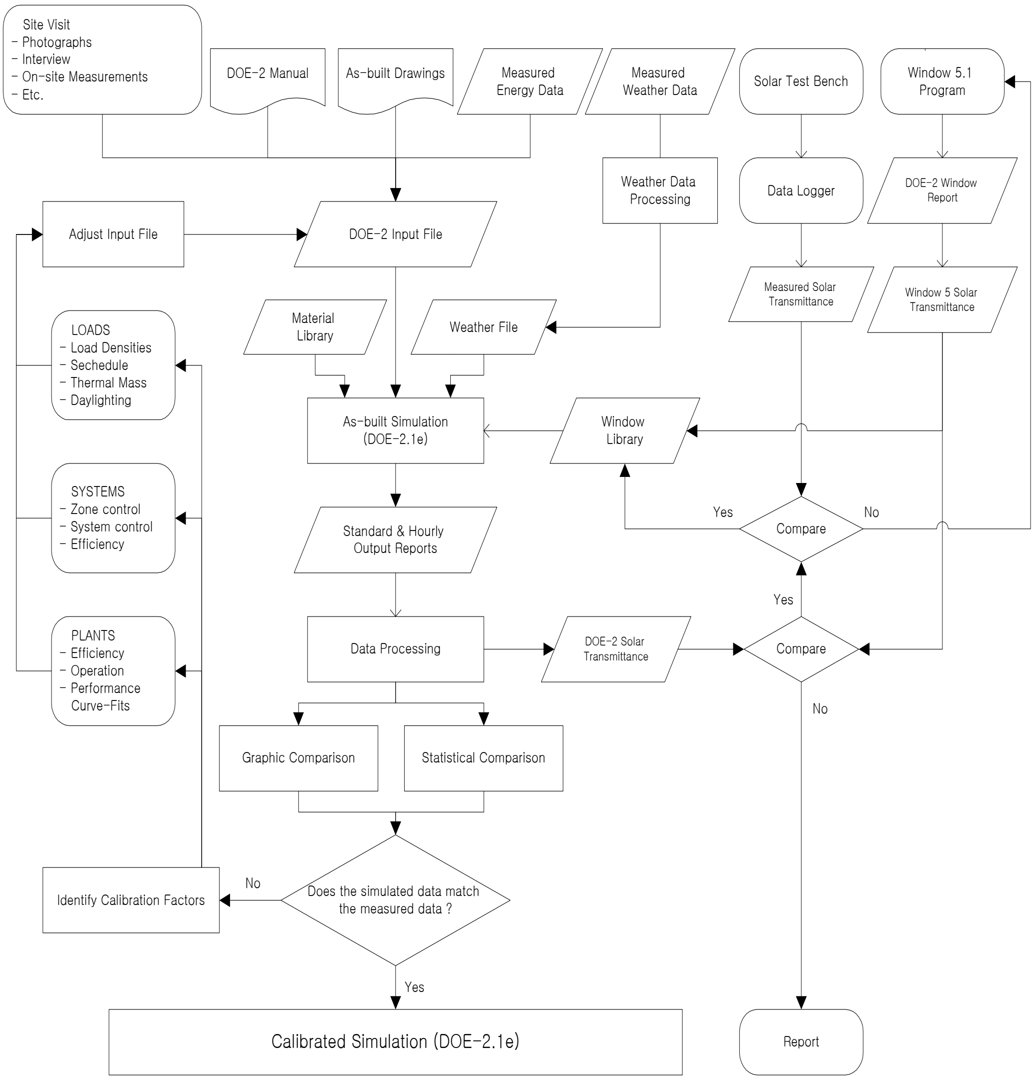


Figure 4.67 *Flowchart of the DOE-2 calibration procedure.*

4.5.2 Weather Data Packed into a Test Reference Year (TRY)

Measured site weather data with solar radiation data were packed into the TRY weather file format and then incorporated into the DOE-2 simulation in this study. Figure 4.68 shows the flow chart that describes the packing of the measured weather data into the TRY format. The NWS weather data were used to generate unpacked TRY data format as shown in Table 4.27, using the LST2TRY program (Bronson, 1992). The NREL solar data were then incorporated into the unpacked TRY file using an EXCEL spreadsheet. Finally, the packed TRY weather file was generated by running the DOE-2 weather processor with the DOE-2 instruction file. Detailed methods are described in the following sub-sections, including: (1) Measured weather data, (2) TRY data, (3) Solar radiation data, and (4) Comparison of measured and packed weather data.

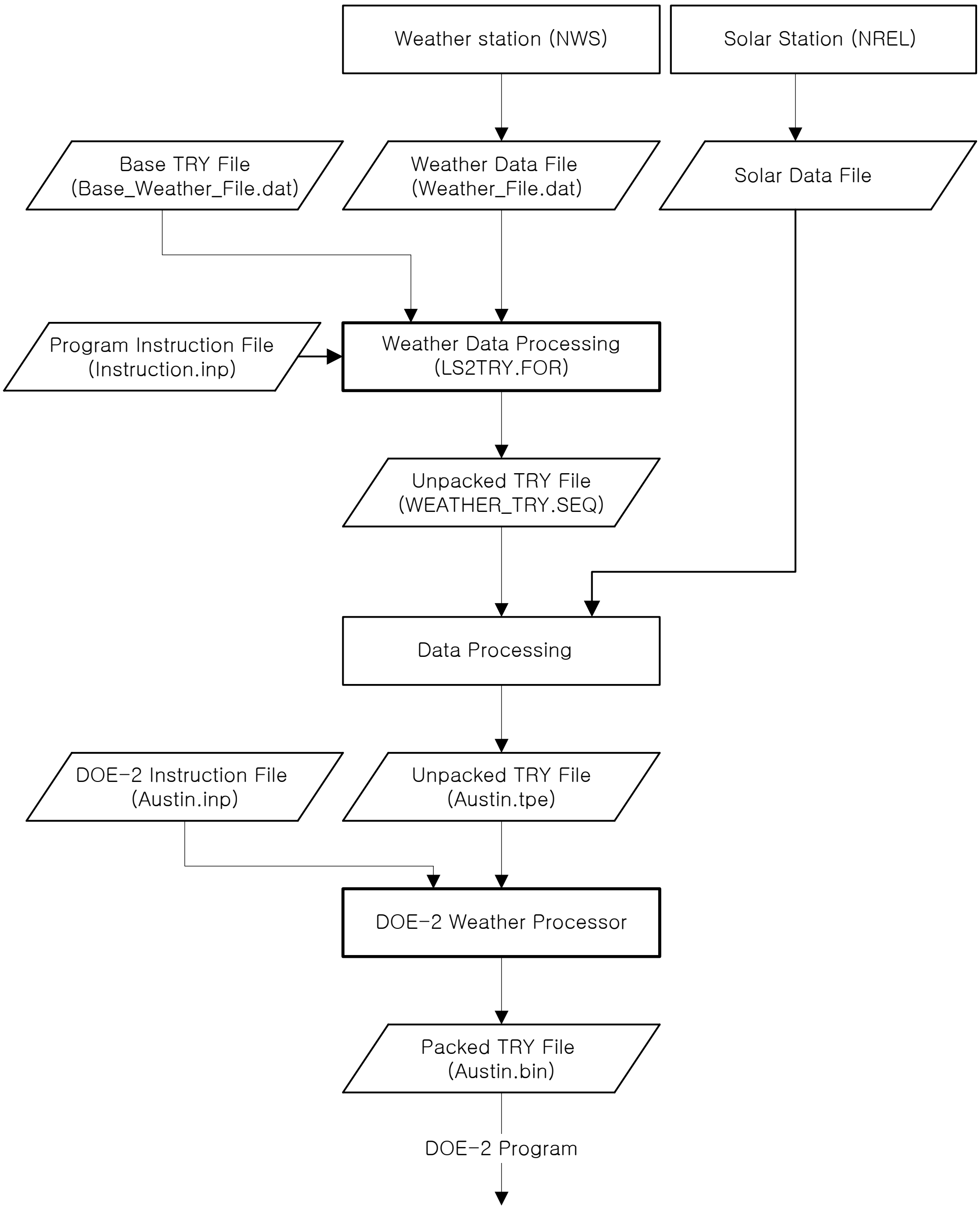


Figure 4.68 *Flowchart of the weather packing into TRY format.*

Table 4.27 TRY Weather Data Format

Field Number	Columns	Element	Remark
001	01 - 05	Station Number	13958
002	06 – 08	Dry-Bulb Temperature	Measured Data
003	09 – 11	Web-Bulb Temperature	Measured Data
004	12 – 14	Dew-Point Temperature	Measured Data
004	15 – 17	Wind Direction	Measured Data
006	18 – 20	Wind Speed	Measured Data
007	21 – 24	Station Pressure	Measured Data
008	25	Weather	0 for no cloud
009	26 – 27	Total Sky Cover	00 for no obstruction
010	28 – 29	Amount of Lowest Cloud Layer	999 for missing
011	30	Type of Lowest Cloud or Obscuring Phenomena	999 for missing
012	31 – 33	Height of Base of Lowest Layer	999 for missing
013	34 – 35	Amount of Second Cloud Layer	999 for missing
014	36	Type of Cloud -Second Layer	999 for missing
015	37 – 39	Height of Base of Second Layer	999 for missing
016	40 – 41	Summation Amount of First Two Layers	999 for missing
017	42 – 43	Amount of Third Cloud Layer	999 for missing
018	44	Type of Cloud – Third Layer	999 for missing
019	45 - 47	Height of Base of Third Layer	999 for missing
020	48 – 49	Summation Amount of First Three Layers	999 for missing
021	50 – 51	Amount of Forth Cloud Layer	999 for missing
022	52	Type of Cloud– Fourth Layer	999 for missing
023	53 – 55	Height of Base of Fourth Layer	999 for missing
024	56 – 59	Global Total Solar Radiation	Measured Data
025	60 – 69	Direct Normal Solar Radiation	Measured Data
026	70 – 73	Year	
027	74 – 75	Month	
028	76 – 77	Day	
029	78 – 79	Hour	
030	80	Blank	

(Note: DOE-2 weather processor recognizes the following solar data in TRY format:
Columns 57-59 Total horizontal radiation in Btu/ft-hr
Columns 61-63 Direct normal radiation in Btu/ft-hr, normally blank).

4.5.2.1 Measured Weather Data

Measured weather data were obtained from two weather stations and a solar station in Austin, Texas, which are located a few miles away from the case-study building, as shown in Table 4.28.

Table 4.28 Weather Station Information

Source	NCDC	NCDC	NREL	REJ
Name	Austin Camp Mabry	Bergstrom International	University of Texas	
Station	ATT	ASU(BSM)		
WBAN No.	13958	13904		
Latitude	30.19’ N	30.11’ N	30.17 N	
Longitude	97.46’ W	97.41’W	97.44 W	
Elevation	658’	480’	700’	

Missing data for less than six hours were filled by linear interpolation, while missing data for more than 6 hours were filled by replacing with those from an adjacent weather station called ASU, as shown in Table 4.29. Appendix C.1 shows time series plots of the hourly measured data before and after the filling of the missing data.

Table 4.29 Summary of the Missing Weather Data

Station Name	Measured data	# of missing data hours (less than 6 hours)	# of missing data hours (more than 6 hours)
NCDC	Dry-bulb Temp. (F)	11	3
	Wet-bulb Temp. (F)	15	3
	Dew-point Temp. (F)	15	3
	Wind Speed (Knot)	0	3
	Station Pressure (InHg)	11	3
NREL	Global Radiation (W/m^2)	0	0
	Direct Normal Radiation (W/m^2)	0	0
	Diffuse Radiation (W/m^2)	0	0

4.5.2.2 Test Reference Year (TRY) Data

As shown in Table 4.27, selected elements were assumed in this study for packing site specific data into a TRY weather format as follows (Bronson 1992):

(1) Hourly observation of weather conditions, such as vision obstruction and the amount and type of cloud cover, are not used by the DOE-2 program when monitored isolation data is available.

(2) The total sky cover parameter was set to ‘00’ for zero cloud cover.

(3) The amount and type of the different cloud layers were set to ‘999’ for missing and unknown.

(4) The value for the occurrence of the weather parameter was set to ‘0’ for no weather or obstruction to vision.

Figure 4.69 shows the instruction file for the DOE-2 weather processor (e.g., AUSTIN.INP) used in this study. Monthly ground temperatures for Austin were automatically calculated as defined in the DOE-2 instruction file, using the method of Kusuda and Achenbach (1965) by DOE-2 weather processor (Buhl, 1999). Figure 4.70 shows an example of the output file (e.g., AUSTIN.TPE).

```
PACK
TRY  AUSTIN
TRY   13958  -999    6 30.3 97.74 30-BITSOLAR    24  20.  .025
1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00
-999.
LIST
PACKED  -999  -999    1    12
STAT
END
```

Figure 4.69 *DOE-2 instruction file (Austin.inp) for packing the measured Austin weather file.*

```
44444034034033180013299700099999999999999999999999999900000000        2001010100
44444034033032180010299700099999999999999999999999999900000000        2001010101
44444034033032180012299700099999999999999999999999999900000000        2001010102
44444034033032180011299700099999999999999999999999999900000000        2001010103
44444034033031180010299700099999999999999999999999999900000000        2001010104
44444034033031180010299700099999999999999999999999999900000000        2001010105
44444033032031180012299700099999999999999999999999999900000000        2001010106
44444032031029180013299700099999999999999999999999999900010000        2001010107
44444033031029180010299700099999999999999999999999999900080000        2001010108
44444033031029180012299700099999999999999999999999999900190001        2001010109
44444033032030180009299700099999999999999999999999999900400001        2001010110
44444034032030180009299700099999999999999999999999999900470001        2001010111
44444035033030180010299700099999999999999999999999999900690004        2001010112
44444034032029180010299700099999999999999999999999999900400001        2001010113
44444035032027180010299700099999999999999999999999999900400001        2001010114
44444034031026180009299700099999999999999999999999999900270001        2001010115
```

Figure 4.70 *An example of the 2001 output file (Autin.tpe).*

4.5.2.3 Solar Radiation Data

As shown in Table 4.27, global and direct normal solar radiations are necessary for packing weather data to the TRY format with solar radiation. Measured solar radiation was used for packing the 2001 weather data into TRY format after replacing bad data with corrected data. Figure 4.71 shows the uncorrected measured data from NREL for Austin, and Figure 4.72 shows corrected measured with calculated diffuse fraction against clearness index (Kt) after trimming bad data. The diffuse fraction of hourly total radiation is strongly correlated with Kt, which is an indicator of the relative clearness of the atmosphere. From the Erbs correlation (Duffie and Beckman 1991), the diffuse radiation (Id) and the beam radiation (Ib) can be estimated in the following equations:

Id/ I = 1.0 – 0.09 Kt For Kt ≤ 0.22 (4.5)

Id/ I = 0.9511-0.1604* Kt + 4.388* Kt^2 – 16.638* Kt^3 + 12.336* Kt^4 For 0.22 < Kt ≤ 0.8 (4.6)

Id/ I = 0.165 For Kt > 0.8 (4.7)

Where, Kt (Hourly clearness index) = I / Io

Where, I= Hourly measured solar radiation for Austin, Texas

Io = Hourly extraterrestrial radiation

$$Io \cong Go = G_{sc}\left(1 + 0.033COS\frac{360n}{365}\right) \times \left[\cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta\right] \quad (4.8)$$

Where, G_O = Hourly extraterrestrial radiation at any time between sunrise and sunset

G_{sc} = Solar constant (1367 W/m^2)

ø = *Latitude (Degree)*

δ = *Solar declination (Degree)*

ω = *Hour angle at the midpoint of the hour (Degree)*

Thus, Id = (Id/ I) * I, Ib = (1- (Id/ I)) * I (4.9)

Figure 4.73 compares the 2001 measured and calculated solar radiation for a selected clear day (7/21/2001). Measure direct normal solar radiation was higher and measured diffuse solar radiation was lower when compared to calculated direct normal and diffuse solar radiation, respectively. Figure 4.74

shows the calculated 2004 diffuse fraction (Id) as a function of clearness index (Kt) with Erbs correlation. Figure 4.75 also compares the 2004 measured global and calculated direct normal solar radiation for a selected clear day (7/15/2004). The simulation results with the measured and calculated direct normal solar radiation are discussed in Chapter VI, Section 6.2.5 for the as-built model calibration.

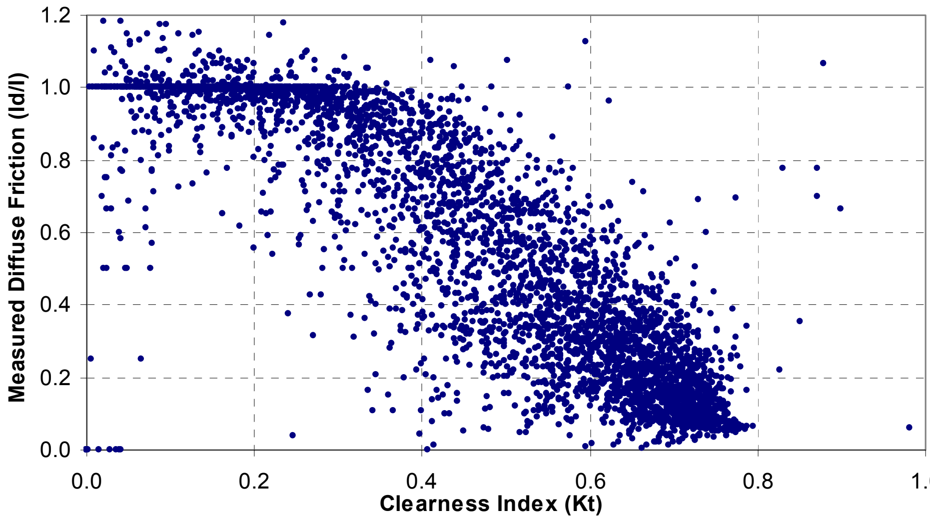


Figure 4.71 *Measured 2001 diffuse fraction against clearness index (Kt).*

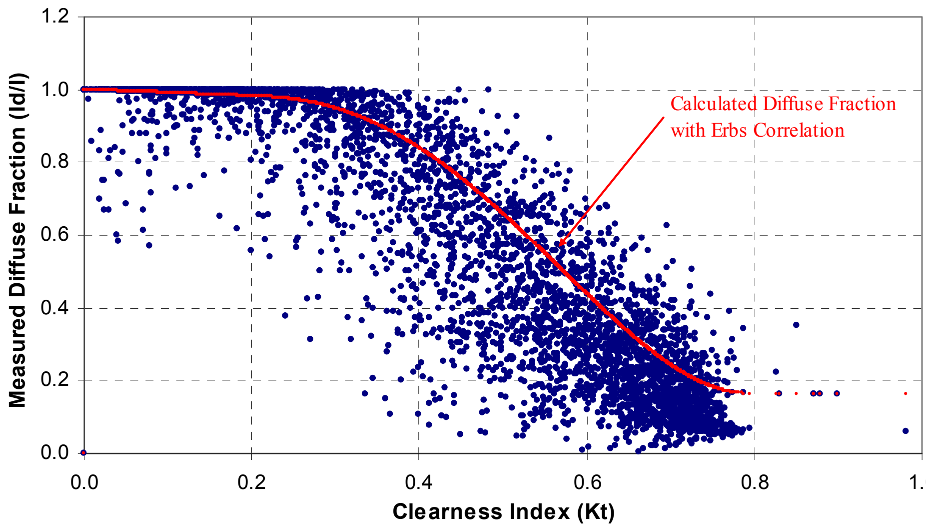


Figure 4.72 *Measured and calculated 2001 diffuse fraction against clearness index (Kt) after bad data clean.*

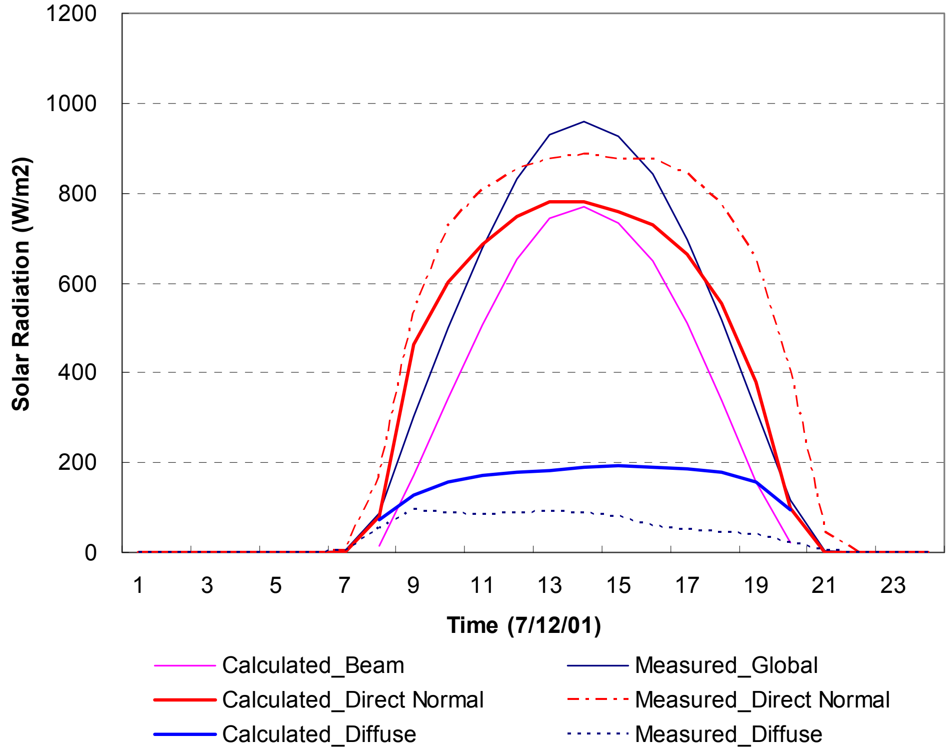


Figure 4.73 *2001 Measured and calculated solar radiation using Erbs correlation for the selected clear day (7/21/2001).*

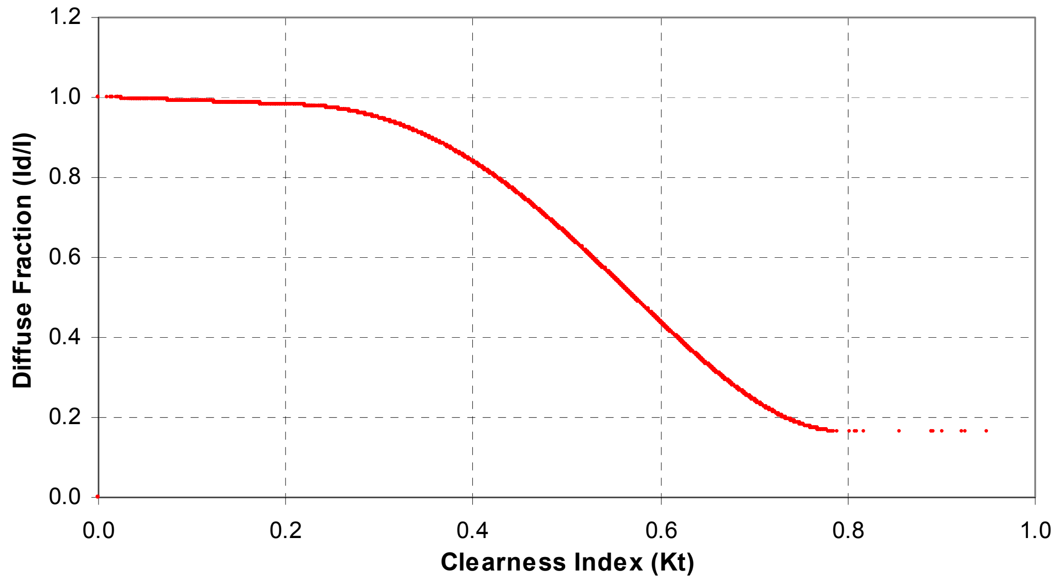


Figure 4.74 *Synthesized 2004 diffuse fraction against clearness index (Kt) with Erbs correlation.*

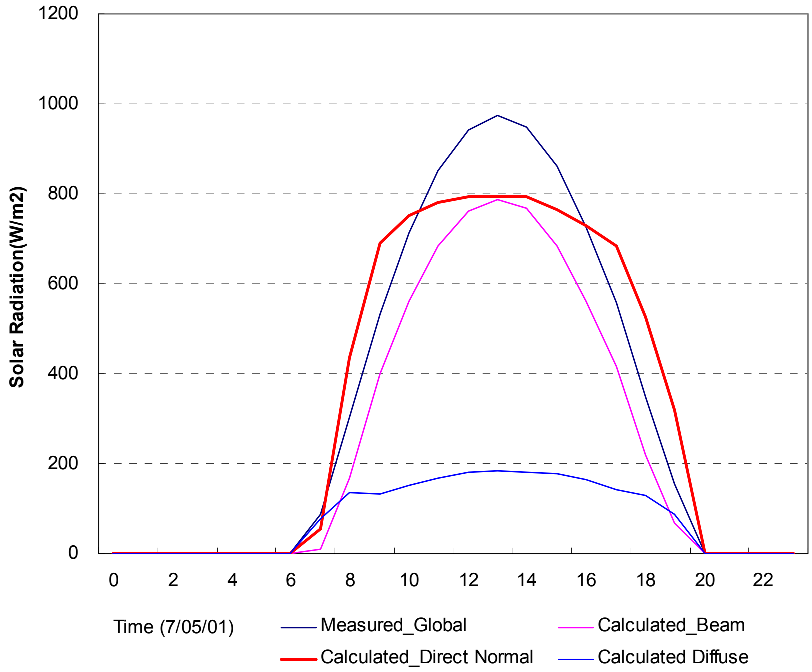


Figure 4.75 *2004 Measured global solar radiation and calculated beam and direct normal solar radiation using Erbs correlation for the selected clear day (7/15/2004).*

4.5.2.4 Comparison of Measured and Packed Weather Data

As a verification of incorporating the measured weather data into the packed TRY file, the measured weather data for 2001 and 2004 were compared against simulation results from the DOE-2 hourly reports. Figure 4.76 shows a comparison of the 2001 measured and packed TRY (DOE-2) weather data, and Figure 4.76 shows a comparison of the 2004 measured and packed TRY (DOE-2) weather data. From the comparison, It was concluded that the measured weather data were successfully incorporated into the TRY weather file for both 2001 and 2004 simulation. It was found that the dew point temperatures calculated in DOE-2 was different from measured data due to decimal points.

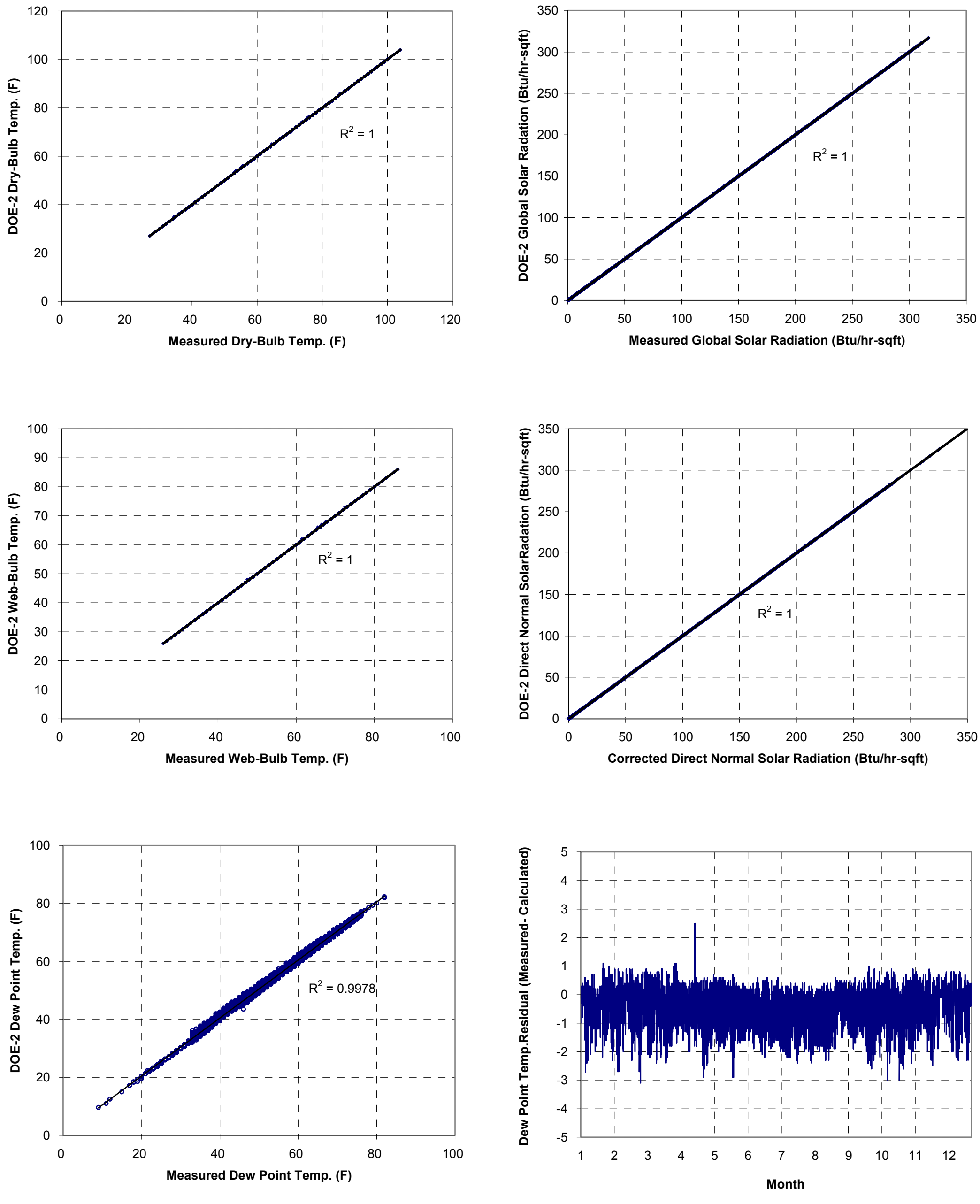


Figure 4.76 *Comparison of 2001 measured and packed TRY (DOE-2) weather data.*

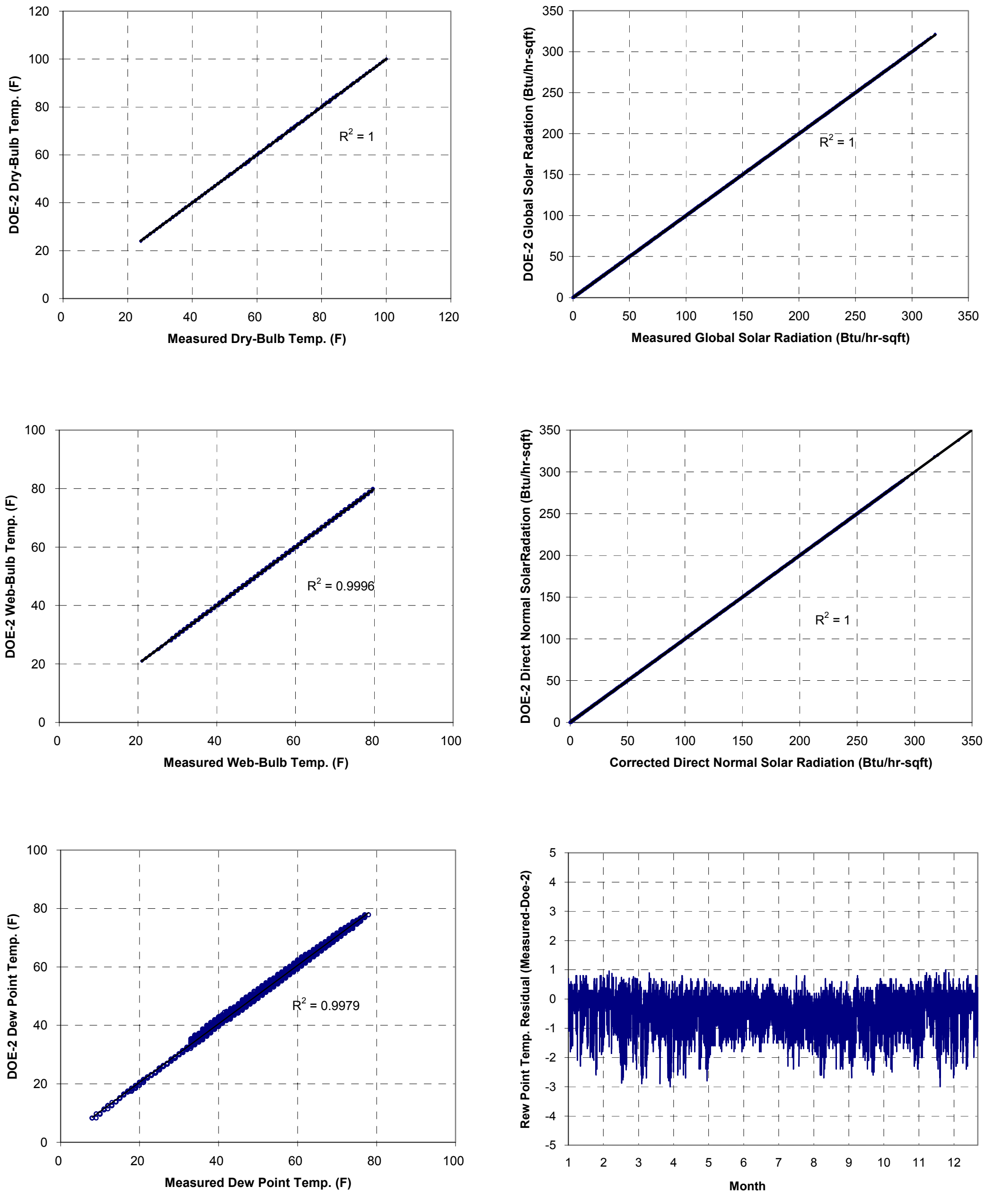


Figure 4.77 *Comparison of 2004 measured and packed TRY (DOE-2) weather data.*

4.5.3 Typical Load Daytyping

As described in Section 4.3.1, the weekday and weekend diversity factors have also been shown to be effective to provide the typical load shapes of lighting and receptacle loads based on analysis developed for ASHRAE Research Project RP-1093 (Abushakra et al. 2001). The 1093-RP daytyping procedure uses 10th, 25th, 50th, 75th, and 90th percentiles for each hour of the day by daytype (i.e., weekday and weekend). As illustrated in Figure 4.78, the 1093-RP diversity factor calculation contains several spreadsheets required for data processing steps. First, all hourly data in columnar 0 to 23 are reformatted into a raw format from 1 to 24. Next, the maximum values (W/sqft) is calculated, which is used to normalize all the hourly data so that the data can be expressed as a 0 to1 index, which is compatible with the DOE-2 input schedule. On the other hand, the 1 to 24, row-oriented, space-delimited data are then designated with schedule-days values (i.e., 1= Sunday, 7=Saturday), and the data sorted into weekdays and weekends groups from which the percentile values are calculated for the two daytypes. For each hour (i.e., each hour represents one column within the weekday-weekend daytype groups), the total, mean, mean $\pm$ one standard deviation, maximum, minimum, 10th, 25th, 50th, 75th, and 90th percentiles are calculated and tabulated. It is recommended that 50th percentile values are used for the diversity factors of the lighting and receptacle loads to be used for the energy calculation, while 90th percentile values are used for peak load calculation. All values are then converted to a scale of 0 to 1, by dividing by the absolute maximum value in the dataset to obtain the weekday-weekend diversity factors in tabular and graphical format. A visual inspection of the load shapes was then used to determine if any of the profiles were inconsistent and/or contained data that needed to be eliminated (i.e., known holidays, shutdowns, etc.). The data associated with low and high values are removed from the dataset and the diversity factors recalculated. Appendix D.2 represents the weekday and weekend loads profiles and diversity factors developed for the case-study building based on measured hourly data.

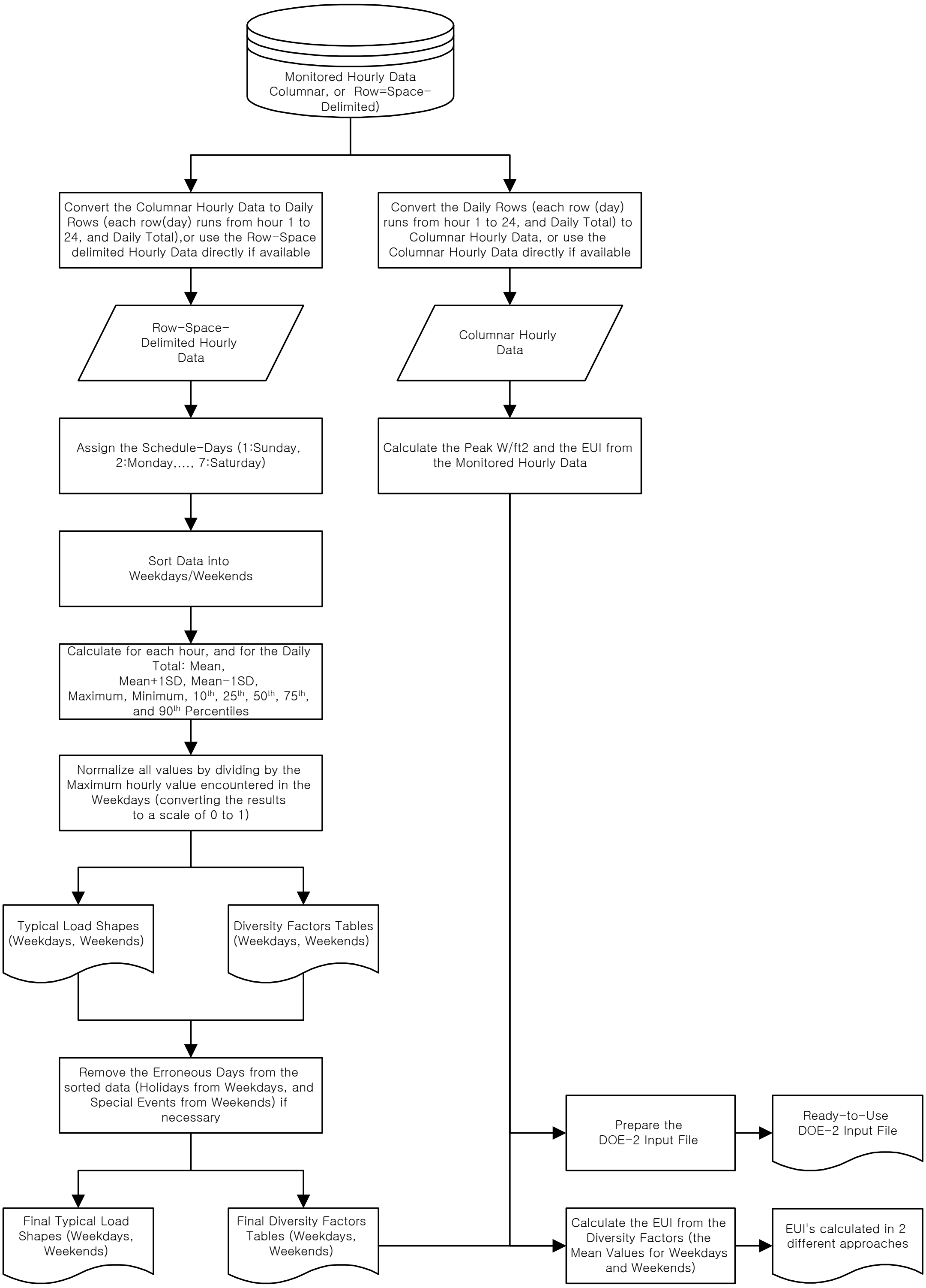


Figure 4.78 *Flowchart of the RP-1093 Method (Abushakra et al., 2001).*

4.5.4 Building Thermal Mass

In DOE-2, the user chooses one of the two weighting factor methods, depending on the type of building and the application (LBL 1982), including: pre-calculated weighting factors, custom weighting factors, and U-effective calculation for underground wall and floor.

ASHRAE Pre-calculated weighting factors are available for users to select the weighting factors that best describe typical constructions from the pre-calculated set. The combined weight of floors, walls, and furniture are considered for the effective thermal mass of the space. Customized weighting factor method is more accurate than the pre-calculated method due to thermal mass effect from the construction in a building. Figure 4.79 shows the load calculation procedure in DOE-2 based on the custom weighting factor method, which considers time delay due to building thermal mass when it comes to space cooling loads. To calculate custom weighting factors in DOE-2 simulation, users should specify FLOOR-WEIGHT=0 and furniture information such as type, fraction, and weight. In addition, each layer of interior, exterior, and underground construction should be specified to account for the response factors.

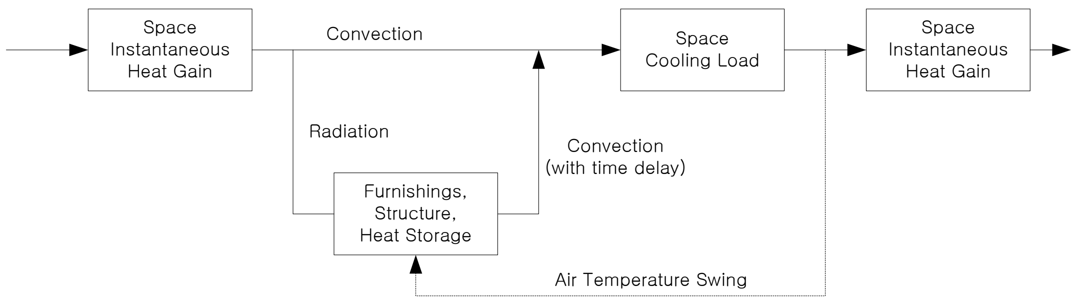


Figure 4.79 *DOE-2 cooling load calculation (LBL 1982).*

According to Fred Winkelmann (1998), heat transfer occurs mainly through the surface's exposed perimeter region rather than uniformly over the whole area of the underground wall and floor. To avoid unrealistically high heat transfer to the ground, U-effective should be used in the UNDERGROUND-FLOOR instruction, and then the response factor for the surface will be used in the custom weighting factor calculation. The DOE-2 program will calculate the heat transfer through the underground surface to be:

$$Q = [U - effecticve] * A * (T_g - T_i) \tag{4.10}$$

Where, U-*effective*= $1/R_{eff}$

A = Surface area

Tg = Ground temperature

Ti = Inside air temperature

Where, $R_{eff} = A/(F2 * P_{\exp})$ (4.11)

F2 = Parameter conduction factor

P_{exp} =Length of the surface perimeter exposed to the outside air.

For the U-effective calculation, a fictitious insulating layer needs to be defined to give correct effective resistance for the construction above a layer of soil, which represents the thermal mass of the ground in contact with the ground surface. Resistance of fictitious layer (R_{fic}) is calculated as the following equation:

$$R_{fic} = R_{eff} - R_{us} - R_{soil} \tag{4.12}$$

Where, R_{us} = Resistance of underground surface and inside film resistance

R_{soil} = 1ft layer of soil (1.0 hr-ft^2 –F/Btu)

Figure 4.80 shows an example of the underground construction model used in this study for the calculation of U-effective using the method by Winkelmann (1998).

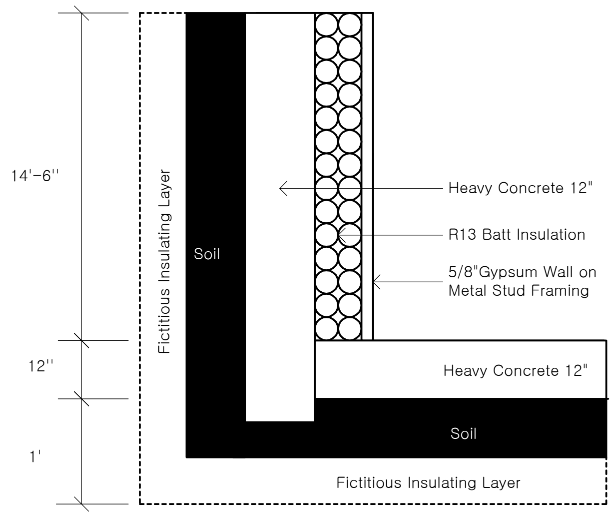


Figure 4.80 *An example of the underground construction model for U-effective calculation.*

4.5.5 Low-e Window Performance

The case study building contains over 50% glazing in the facade consisting of two types of energy efficient, low-E glazing. DOE-2.1E retains the two window calculation methods available in early versions of the program: (1) ‘ASHRAE shading coefficient approach’ in which the solar heat gain for standard clear glass is calculated and then multiplied by the shading coefficient of the glazing being modeled, and (2) the ‘glass-type-code approach’ in which the users match the glazing to be modeled with one from a library, which is separated into two groups based on the glass-typed-code. The pros and cons of the different methods are compared in Table 4.30.

Table 4.30 Pros and Cons of the DOE-2 Window Calculation Methods

Methods	Pros	Cons
1. Shading coefficient	Convenient for conceptual design	Inaccurate angular dependence for multipane glazing
2. Glass-type-code ≤ 11	More accurate angular dependence	May not be good match to actual glazing
3. Window library Glass- Type-code ≥1000	Highly accurate angular dependence and conduction; user can expand library	50~100% increase in LOADS calculation time depending on number of windows

Furthermore, DOE-2.1E is incapable of modeling the thermal and optical behavior of windows in detail using the Window 5 program, which adopts the NFRC (National Fenestration Rating Council) procedure for calculating the thermal performance of Window (Reilly et al., 1995) such as center-of-glazing U-Factor (U), Solar Heat Gain Coefficient (SHGC), and Visible Transmittance (VT). Figure 4.81 and Figure 4.82 show the Window 5 program showing the glazing layer and thermal and optical properties generated for the two types of low-e window used in this study. Once a DOE-2 window report is generated from the Window 5 program, it is added to the DOE-2 window library for DOE-2 simulation. Appendix F.2 shows the DOE-2 window reports from the Window 5.2 program for the case-study building. Figure 4.83 and Figure 4.84 show the window properties (i.e., transmissivity) against angle of incidence, which is generated from Window 5 for the upper and lower low-e glazing for the case-study building. Solar transmittance from Window 5 is compared to the DOE-2 simulation to see if the window library is incorporated into the DOE-2 simulation based on the test glazing on the top of the DOE-2 simulation model, which is described in Chapter VI. Section 6.1.1.3.

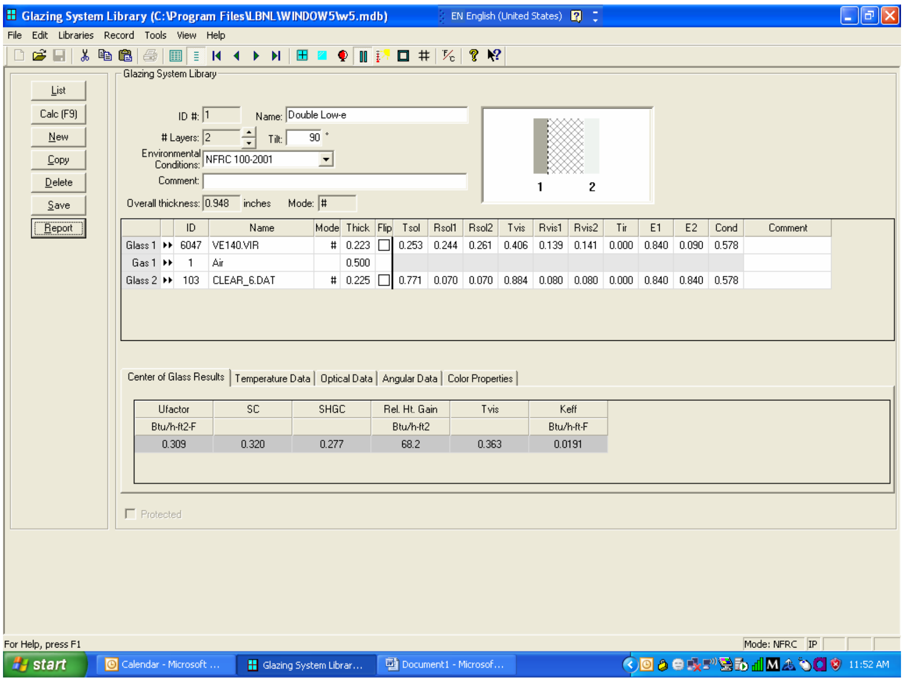


Figure 4.81 *Window 5 screen for the low-e glazing of the case-study building (Upper part).*

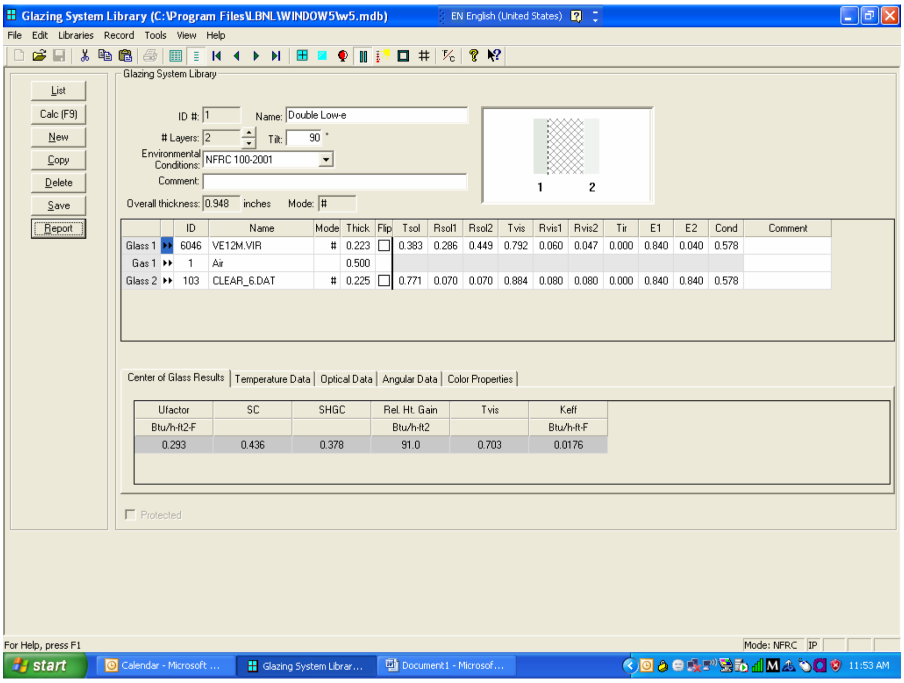


Figure 4.82 *Window 5 screen for the low-e glazing of the case-study building (Upper part).*

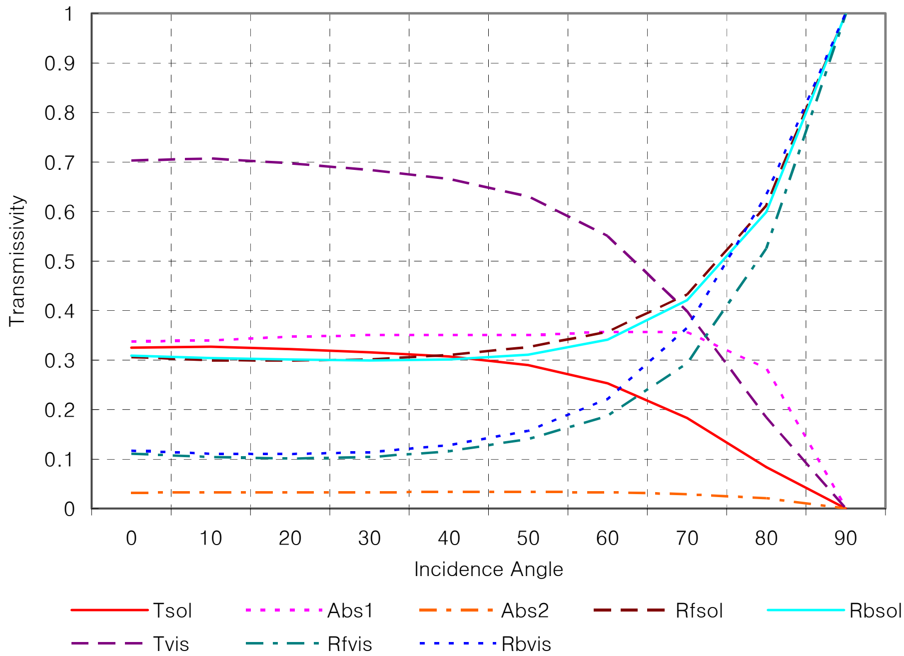


Figure 4.83 *Transmissivity vs. angle of incidence for upper low-e glazing.*

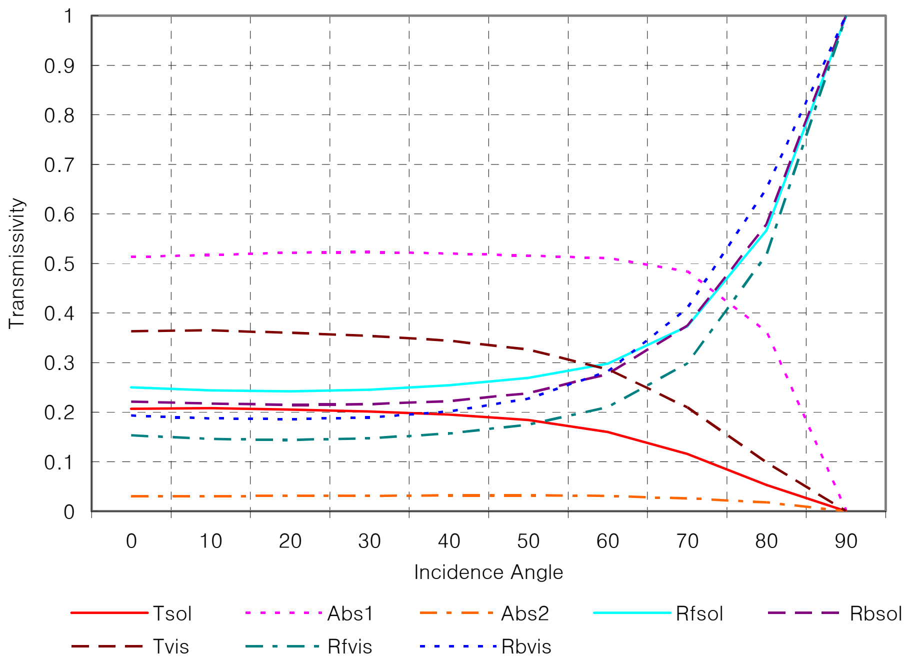


Figure 4.84 *Transmissivity vs. angle of incidence for lower low-e glazing.*

4.5.6. HVAC System Performance

In DOE-2, HVAC equipment efficiency is determined in general by the ratio of energy input to energy output at full load (normal capacity) such as Electric Input Ratio (EIR) for the equipment requiring electric power input (e.g., chiller, fan, and pump) and Heat Input Ratio (HIR) for the equipment requiring fuel input (e.g., boiler). In this study, the DOE-2 default efficiency was first adjusted with measured data or manufacturer data to account for the actual HVAC performance at normal operation condition. Table 4.31 compares the efficiency between DOE-2 default and actual performance values used in this study.

Table 4.31 Primary Equipment Efficiency of the REJ building

Items	Type	Size		Efficiency	
		Default	Input (MMBtu/hr)	DOE-2 Default	Input
Boiler	Hot water	From load	5	1.25 (HIR)	1.19 (HIR)
Chiller	Centrifugal	From load	5.58	0.192 (EIR)	0.15 (EIR)
Cooling Tower	Open tower	From load	12	0.0105 (EIR)	0.0098 (EIR)
Pump	Fixed speed	From peak	Inst-plant-equip	60	35 (Head)
Fan	Variable speed	From load	From load	0.9	0.51

For part-load conditions, DOE-2 default curves are designed to represent typical equipment performance. Table 4.32 describes the DOE-2 curve types (linear, bi-linear, quadratic, bi-quadratic, or cubic) and Table 4.33 shows DOE-2 keywords and corresponding independent variables for equipment. Table 4.34 specifies the coefficients for each DOE-2 equipment curve and Figure 4.85 illustrates the selected DOE-2 performance curves as a function of Part-load ration (PLR). In DOE-2, it is possible for a user to override the default curves with a new curve to suit the user’s chosen equipment if it is different from the default performance curve. In this study, one of the chiller performance curve fits (e.g., OPEN-CENT-EIR-FPLR) was developed as a function of part-load ratio using actual measured chiller data from the case-study building.

Table 4.32 DOE-2 HVAC Equipment Default Curves and Description

Items	Keywords	Description	Curve Type
Boiler	HW-BOILER-HIR-FPLR	Heat input ratio correction factor	QUAD
Chiller	OPEN-CENT-CAP-FT	Operating capacity correction factor	BI-QUAD
	OPEN-CENT-EIR-FPLR	Electric input ratio correction factor	QUAD
	OPEN-CENT-EIR-FT	Electric input ratio correction factor	BI-QUAD
HVAC	COOL-CAP-FT	Cooling coil capacity	BI-QUAD
	COOL-SH-FT	Sensible heat removal capacity of air cooling device	BI-QUAD
	COIL-BF-FFLOW	Coil bypass factor	QUAD
	COIL-BF-FT	Coil bypass factor	BI-QUAD
	RATED-CCAP-FFLOW	Rated cooling capacity	QUAD
	RATED-SH-FFLOW	Rated cooling sensible capacity	QUAD
	RATED-HCAP-FFLOW	Rated heating capacity	LINEAR
Cooling Tower	TWR-FAN-FPLR	Tower fan horsepower	CUBIC
	TWR-GPM-FPA	An intermediate variable	BI-QUAD
	TWR-GPM-FWB	The current tower capacity relative to the capacity at the CTI design condition	BI-QUAD
	TC-CHLR-CAP-FT	Chiller capacity as a function of condenser and chilled water temp while operating in the direct cooling	BI-QUAD

Table 4.33 DOE-2 HVAC Equipment Default Curves and Independent Variables

Items	DOE-2 Keywords	Independent variables	Description	Remarks
Boiler	HW-BOILER-HIR-FPLR	PLR	Part-load ratio (fraction) = Fuel input / heating output	-
Chiller	OPEN-CENT-CAP-FT	Tout	Leaving chilled water temp.	-
		Tin	Entering condenser water temp.	
	OPEN-CENT-EIR-FPLR	PLR (1/COP)	Part-load ratio (fraction) = Energy Input(kW) *3413 / Cooling output(ton)*12000	-
	OPEN-CENT-EIR-FT	Tout	Leaving chilled water temp.	-
		Tin	Entering condenser water temp.	
HVAC	COOL-CAP-FT	WB	Entering WB temp. for chilled water coils	-
		DB	Entering DB temp. for chilled water coils	-
	COOL-SH-FT	WB	Entering WB temp. for chilled water coils	-
		DB	Entering DB temp. for chilled water coils	-
	COIL-BF-FFLOW	CFM	Supply air flow rate	-
		PLR	Part-load ratio (fraction)	-
	COIL-BF-FT	WB	Entering WB temp.	-
		EDB	Entering DB temp.	-
	RATED-CCAP-FFLOW	CFM	Supply air flow rate	-
		PLR	Part-load ratio (fraction) =Supply air flow/ rated cfm	-
	RATED-SH-FFLOW	CFM	Supply air flow rate	-
		PLR	Part-load ratio (fraction) =Supply air flow/ rated cfm	-
	RATED-HCAP-FFLOW	CFM	Supply air flow rate	-
		PLR	Part-load ratio (fraction) =Supply air flow/ rated cfm	-
Cooling Tower	TWR-FAN-FPLR	ARCELL	Number of cooling tower units per cell	-
	TWR-GPM-FPA	RNG	Range, temperature drop through tower	-
		APP	Approach, temperature difference	-
	TWR-GPM-FWB	FRA	TWR-GPM-FRA	-
		OWB	Outside Web-bulb temp	-
	TC-CHLR-CAP-FT	Tcond	Condenser water temp	-
		Tcw	Chilled water temp	-

Table 4.34 Coefficients for DOE-2 HVAC Equipment Default Curves

Equipment	DOE-2 Keywords	Default U-name	Type of Curve	Independent Variable(x,y)	Coefficient					
					a	b	c	d	e	f
HW Boiler	HW-BOILER-HIR-FPLR	-	QUAD	PLR	0.0825970	0.9967640	-0.0793610	-	-	-
Chiller (Herm-Centrifugal)	HERM-CENT-CAP-FT	CCAPT1	BI-QUAD	TOUT,TIN	-1.7420400	0.0292920	-0.0000670	0.0480540	-0.0002910	-0.0001060
	HERM-CENT-EIR-FPLR	EIRPLR1	QUAD	PLR	0.2229030	0.3133870	0.4637100	-	-	-
	HERM-CENT-EIR-FT	EIRT1	BI-QUAD	TOUT,TIN	3.1175000	-0.1092360	0.0013890	0.0037500	0.0001500	-0.0003750
HVAC (DDVAV)	COOL-CAP-FT	SDL-C7	BI-QUAD	WB,DB	2.5882585	-0.2305879	0.0038359	0.1025812	0.0005984	-0.0028721
	COOL-SH-FT	SDL-C27	BI-QUAD	WB,DB	0.8982767	-0.1312367	0.0019688	0.089664	0.0005703	-0.0020087
	COIL-BF-FCFM	SDL-C38	QUAD	CFM,PLR	-0.2542341	1.2182558	0.0359784	0	0	0
	COIL-BF-FT	SDL-C48	BI-QUAD	WB,EDB	1.0660053	-0.000517	0.0000567	-0.0129181	-0.0000017	0.0001503
	RATED-CCAP-FCFM	SDL-C80	QUAD	CFM-PLR	0.1888321	1.0928053	-0.2816374	0	0	0
	RATED-SH-FCFM	SDL-C87	QUAD	CFM-PLR	0.2015452	0.8553716	-0.0570167	0	0	0
	RATED-HCAP-FCFM	SDL-C102	LINEAR	CFM-PLR	1	0	0	0	0	0
Cooling Tower (Open type)	TWR-FAN-FPLR	TWRFAN	CUBIC	ARCEL	0.3316229	-0.8856761	0.6055651	0.9484823	0.0000000	0.0000000
	TWR-GPM-FRA	GPMRA	BI-QUAD	RNG,FRA	-2.2288890	0.1667954	-0.0141025	0.0322233	0.1856021	0.2425187
	TWR-GPM-FRB	GPMRB	BI-QUAD	FRA,OWB	0.6053140	-0.0355454	0.0080408	0.0286026	0.0002497	0.0049086
	TC-CHLR-CAP-FT	CCAPT5	BI-QUAD	Tcond, Tcw	-0.3514430	0.0565830	-0.6000540	-0.0456250	-0.0000430	-0.0000120
Fan	-	-	CUBIC	PLR	0.0015300	0.0052000	1.1086000	-0.1164000	-	-
Pump	CIRC-PUMP-FPLR	CIRC-PUMP	CUBIC	PLR	0.0015303	0.0052081	1.1086242	-0.1163556	-	-

Figure 4.86 compares the measured chiller performance curves with DOE-2 default curve for each chiller. Measured chiller performance curves for each chiller are almost identical and also close to the DOE-2 default curve. Figure 4.87 compares the measured total chiller (1+2) performance curve with DOE-2 default curve. It was found that the two chillers were operated in either parallel (upper part curve) or sequence (lower part curve) at below 0.6 part-load ratio. Therefore, a method of switching chiller performance curves needs to be developed to account for actual operation with either parallel or sequence operation at part-load conditions. In this study, the DOE-2 default chiller curve was used because the measured curves are not quite different from the DOE-2 default as shown in Figure 4.86 and Figure 4.87. The other HVAC systems also followed the DOE-2 default curves.

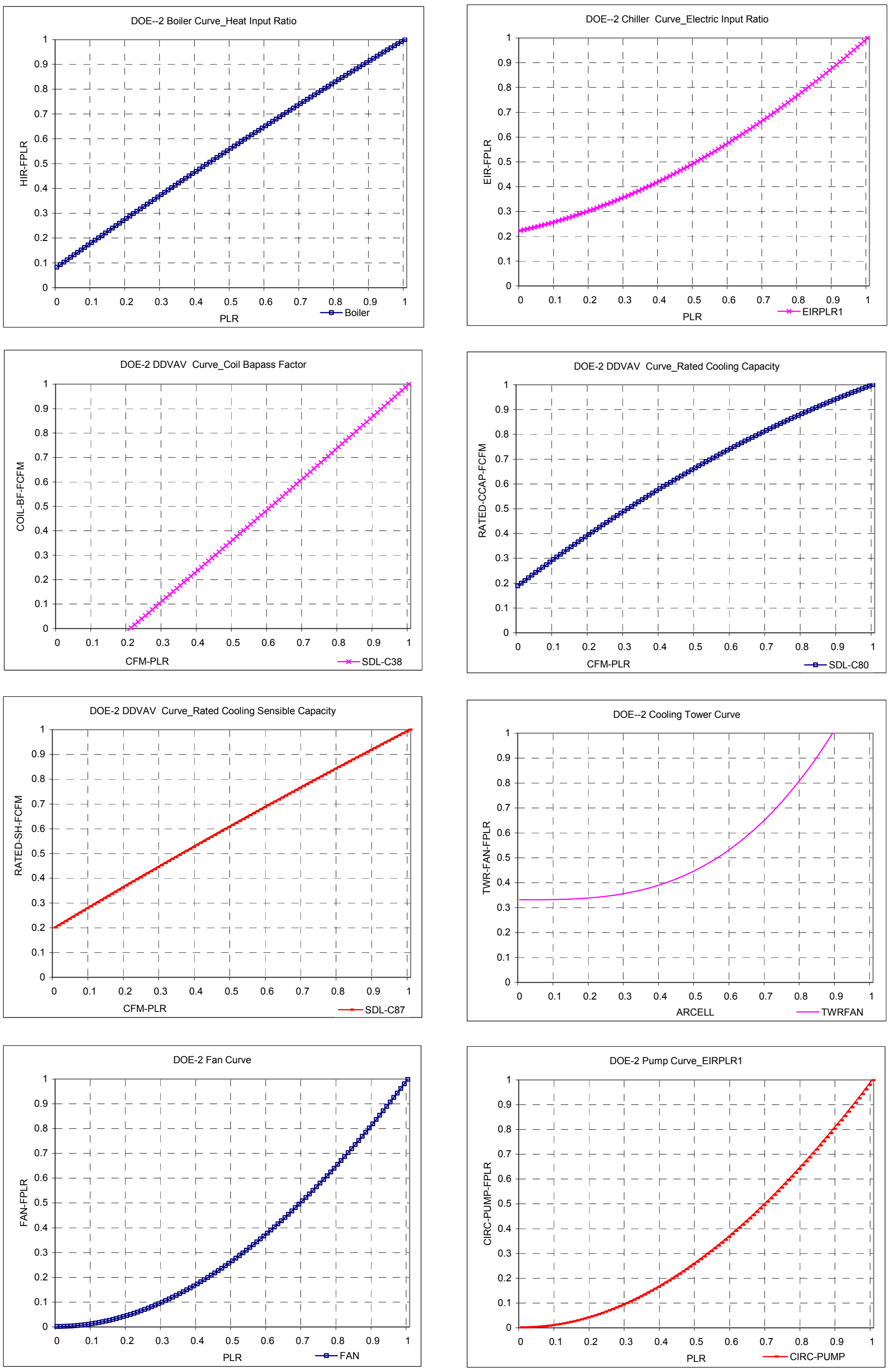


Figure 4.85 *DOE-2 HVAC performance curves.*

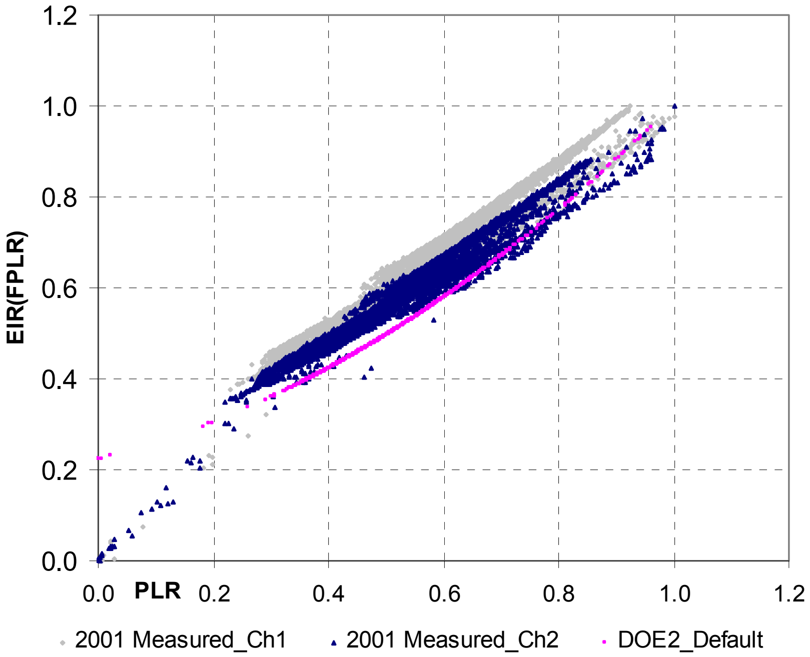


Figure 4.86 *Measured chiller performance curves for each REJ chiller.*

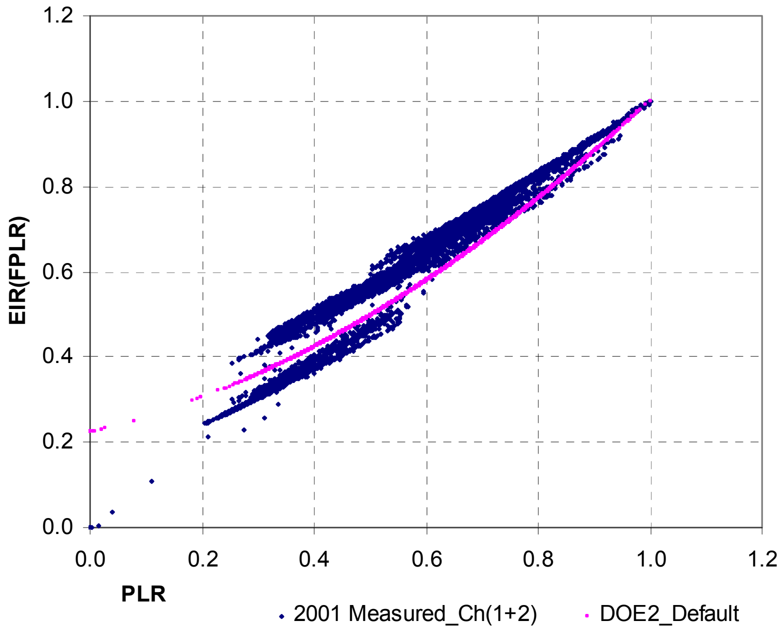


Figure 4.87 *Measured chiller performance curve for the REJ chillers (1+2).*

4.5.7 Graphical and Statistical Analysis

4.5.7.1 Signature Analysis Methods

Two types of energy signatures have been developed in this study, including calibration signatures and characteristic signatures. The calibration signatures represent graphical deviation between measured energy consumption and simulated energy consumption as a function of average dry bulb-temperature (Claridge et al., 2003). The calibration signatures have been shown to be useful for calibrating the simplified engineering model such as "Air-model." The calibration signatures are developed using the following equation in terms of heating, cooling, and whole-building electricity use:

$$Calibration\ \ Signature = \frac{-Residual}{Maximum\ \ measured\ \ energy} \times 100 \tag{4.14}$$

Where, Residual = Simulated Energy Use – Measured Energy Use

In this study, the signature concept is enhanced with percentile expression for applying to the detailed whole-building simulation using DOE-2 program. Figure 4.88 shows an example of the calibration signatures with 25^{th}, 50^{th}, and 75^{th} percentiles developed for the case-study building. Chapter VI shows all the calibration signatures from each simulation for the DOE-2 calibration of the case-study building. Characteristic signatures represent a sensitivity analysis in each parameter for a building and system level. In other words, the characteristic signatures provide a predictable shape according to changing an input parameter by a certain amount of value based on the calibration signatures. Figure 4.89 shows an example of the characteristic signatures developed in this study for the DOE-2 calibration of the case study building. Each characteristic signature is a sort of graphical clue in what simulation parameters and how much parameter values should be changed to improve the simulation results when compared with calibration signatures. The characteristic signature is developed by the following equation:

$$Characteristic\ \ Signature = \frac{Change\ in\ energy\ consumption}{Maximum\ \ energy\ consumption} \times 100 \tag{4.15}$$

Where, Change in energy consumption = Simulated Energy Use after Input Change
– Simulated Baseline Energy Use

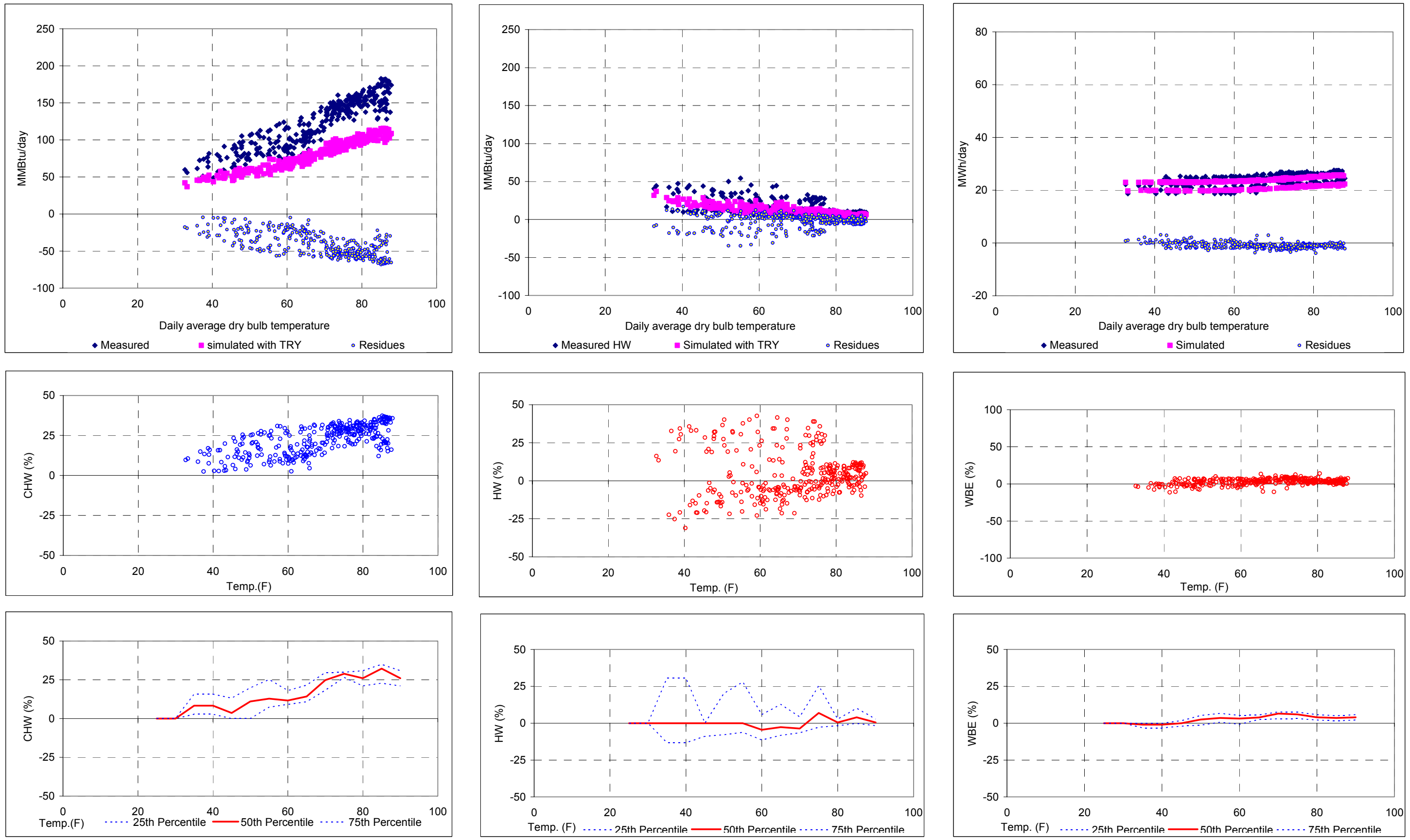


Figure 4.88 *An example of the calibration signatures developed for the case-study building.*

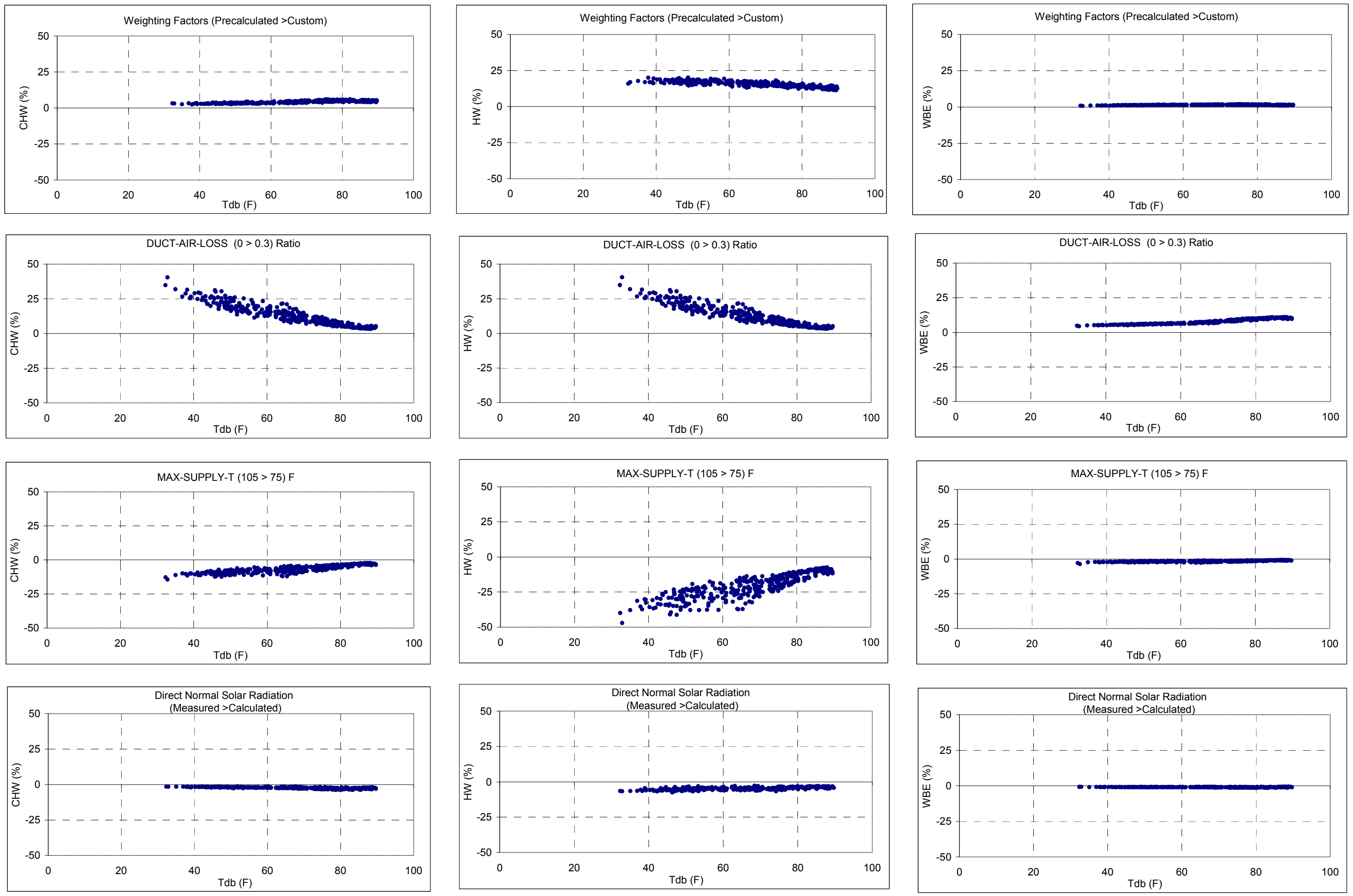


Figure 4.89 *An example of the characteristic signatures developed for the case-study building.*

4.5.7.2 Statistical Analysis Methods

Several statistical methods have also been developed to assess the goodness-of-fit of a simulation model, including: percent difference, mean bias error (MBE), and use of the coefficient of variation of the root mean square error (CV(RMSE)) (Kreider and Haberl, 1994). The mean bias error (MBE) is a method to determine a non–dimensional bias measure between the simulated data and the measured data for each individual hour. The coefficient of variation of the root mean square error (CV(RMSE)) is essentially the root mean square error divided by the measured mean of all the data. These statistical methods will be used in this study to determine how well the simulation model fits the data in the process of calibration (i.e., the lower the CV(RMSE), the better the calibration) (Haberl and Bou-Saada, 1998). The Coefficient of Variation CV (%) and Mean Bias Error, MBE (%) can be calculated by the following equations, respectively:

$$CV\ (RMSE\ ) = \frac{\sqrt{\dfrac{\sum_{i=1}^{n} (Ypred\ ,i - Ydata\ ,i)2}{n-p}}}{ydata} x100 \tag{4.16}$$

$$MSE\ = \frac{\dfrac{\sum_{i=1}^{n} (Ypred\ - Ydata\ ,i)}{n-p}}{ydata} x100 \tag{4.17}$$

Where,

$Y_{\text{data, i}}$ is a data value of the dependent variable corresponding to a particular set of the independent variables,

$Y_{\text{pred, i}}$ is a predicted dependent variable for the same set of the independent variables,

Y_{data} is the mean value of the dependent variable of the data set,

n is the number of data point in the data set, and

p is the total number of regression parameters in the model.

4.5 Summary of the Methodology

To accomplish the purpose and objectives above, several methods were developed and used in this study, in terms of 1) Energy Measurement and Verification (M&V), 2) Simulation and calibration methods, and 3) Building energy baselines and savings assessments.

Whole-building energy metering and in-situ measurements for selected components including: low-e glazing, high-efficiency chiller, and dual-duct air handling units were performed. As a result, several new methods were analyzed and developed in this study, including: 1) Development of procedures to synthesize weather-normalized cooling energy use (i.e., Btu cooling production) from a correlation of MCC electricity use, and a chiller performance curve, 2) Development of methods to analyze measured solar transmittance against incidence angle for sample glazing using different solar sensor types, including an Eppley PSP and Li-Cor sensor, 3) Development of methods to analyze chiller efficiency and operation at part-load condition, and 4) Development of methods to analyze measured AHU system operation for DOE-2 calibration.

Simulation and calibration methods applicable to new commercial buildings were developed and used, including: measured weather data packed into TRY format, typical load day-typing, building thermal mass, low-e window performance, HAVC system performance, and graphical and statistical evaluation. Several new methods were also analyzed and developed in the process of the as-built model simulation and calibration, including: 1) Improvement to the previous signature method (Wei et al. 1998) by adding percentile analysis for use with a DOE-2 calibration, and 2) Comparison of the measured solar transmittance against incidence angle for low-e glazing with DOE-2 output and window library generated using the Window 5.2 program.

Different energy baselines were developed to calculate actual energy savings, including: a code-compliant baseline with ASHRAE Standard 90.1-1989 (ASHRAE 1989) vs. Standard 90.1-2001 (ASHRAE 2001), a comparison of design conditions without ECDMs, and a comparison to reference buildings in a control group.

CHAPTER V

MEASURED DATA FROM THE CASE-STUDY BUILDING

Measured data from the case-study building were analyzed to verify as-built building energy performance and operations for the period 2001 and 2004, including: 1) utility billing data, whole-building energy use, and component performance such as such as chiller efficiency, typical AHU operation, and solar transmittance of low-e glazing.

5.1 Utility Billing Data

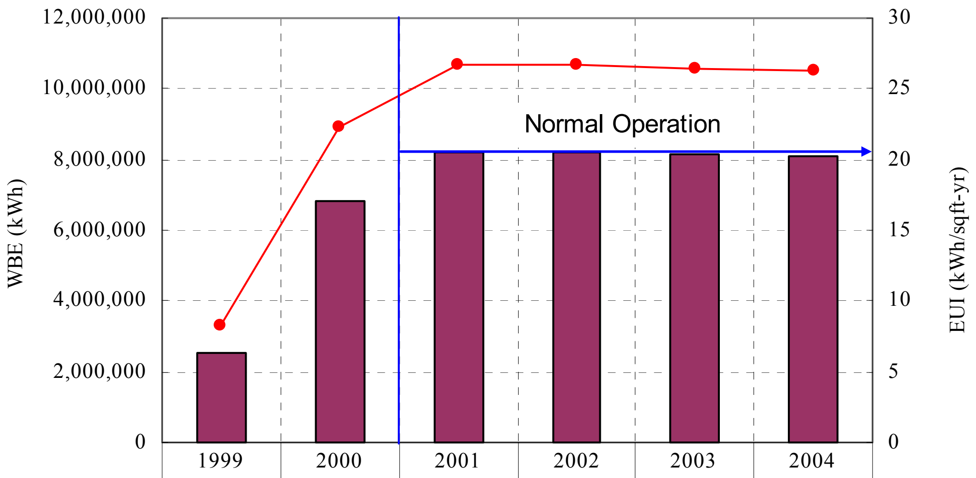
5.1.1 Electricity Energy Use

Monthly electricity billing data for several years were analyzed to identify energy use trend since 1998 and then compared to the measured data for the years 2001 and 2004. Table 5.1 shows the monthly electricity utility bills from City of Austin for the period from January 1999 to December 2004. Figure 5.1 illustrates the whole-building electricity (WBE) and energy use intensity (EUI) for the period 1999 to 2004.

Table 5.1 Comparison of Electricity Energy Use (1999-2001)

Year / Month	Utility Billing Data						Measured Data	
	1999	2000	2001	2002	2003	2004	2001	2004
1	2,000	340,000	724,000	698,000	716,000	680,000	608,614	682,109
2	84,000	402,000	672,000	642,000	744,000	616,000	655,414	601,664
3	128,000	494,000	716,000	784,000	710,000	740,000	719,449	684,586
4	174,000	536,000	768,000	748,000	718,000	718,000	732,764	702,714
5	198,000	706,000	812,000	758,000	784,000	692,000	794,176	748,253
6	320,000	706,000	740,000	734,000	790,000	822,000	748,538	731,285
7	344,000	682,000	838,000	832,000	772,000	772,000	797,762	780,362
8	362,000	862,000	784,000	764,000	736,000	864,000	772,605	776,753
9	352,000	706,000	700,000	768,000	780,000	704,000	718,863	737,725
10	276,000	714,000	746,000	772,000	698,000	784,000	721,722	731,704
11	292,000	682,000	716,000	708,000	674,000	688,000	674,122	652,808
12	308,000	648,000	724,000	724,000	800,000	706,000	685,925	653,441
Total	2,533,999	6,832,000	8,218,001	8,210,002	8,124,003	8,082,004	7,946,028	7,831,968
EUI(kWh/yr-sqft)	8	22	27	27	26	26	26	26
EUI(kBtu/yr-sqft)	28	76	91	91	90	90	88	87

As shown in Figure 5.1, the case-study building has started to operate normally since 2001. A small difference in electricity use can be seen from 2001 to 2004. Therefore, 2001 and 2004 measured data were used in this study for the performance evaluation of the case-study building. Measured data were verified with monthly utility data for 2001 and 2004 as shown in Figure 5.2.



	1999	2000	2001	2002	2003	2004
WBE	2,533,999	6,832,000	8,218,001	8,210,002	8,124,003	8,082,004
EUI	8	22	27	27	26	26

Figure 5.1 *Comparison of REJ electricity billing data (1999-2001).*

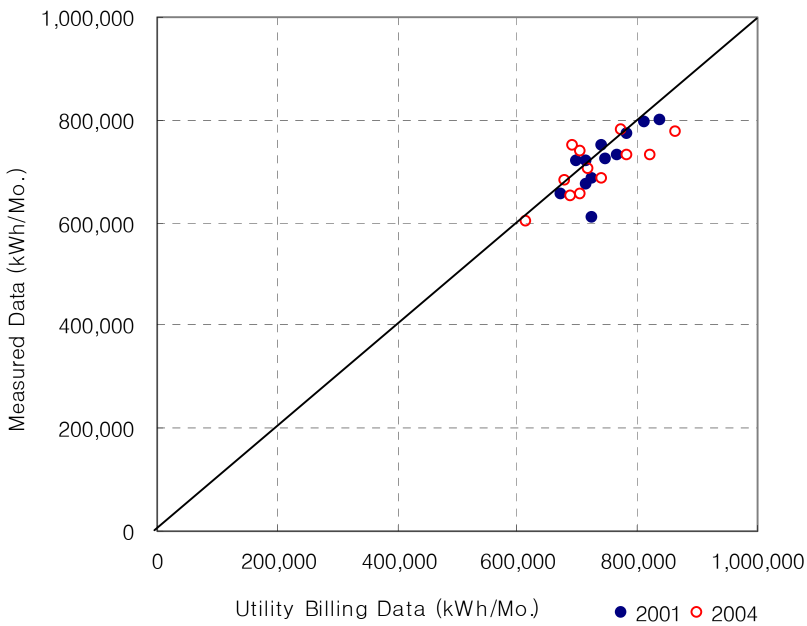


Figure 5.2 *Comparison of REJ electricity use between utility billing and measured data (2001 and 2004).*

Since the billing dates did not correspond exactly to the calendar month, electricity utility billing data for 2001 and 2004 were divided by number of days for each month as shown in Table 5.2 and Table 5.3.

Table 5.2 REJ Monthly Electricity Utility Billing Data for 2001

Utility Bulling Date					Consumption		Demand	Tdb (F)
Month	Day	Year	date	Days/ Mo	kWh/Mo	kWh/day	kW/Mo	
Jan	31	2001	01/31/01	32	724,000	22,625	1300.0	41.72
Feb	28	2001	02/28/01	28	672,000	24,000	1300.0	51.25
Mar	30	2001	03/30/01	30	716,000	23,867	1320.0	48.57
Apr	30	2001	04/30/01	31	768,000	24,774	1280.0	63.97
May	31	2001	05/31/01	31	812,000	26,194	1300.0	68.32
Jun	29	2001	06/29/01	29	740,000	25,517	1340.0	72.90
Jul	31	2001	07/31/01	32	838,000	26,188	1360.0	77.29
Aug	31	2001	08/31/01	31	784,000	25,290	1340.0	75.87
Sep	28	2001	09/28/01	28	700,000	25,000	1300.0	69.71
Oct	29	2001	10/29/01	31	746,000	24,065	1340.0	52.97
Nov	29	2001	11/29/01	31	716,000	23,097	1340.0	56.00
Dec	31	2001	12/31/01	32	724,000	22,625	1280.0	47.63

Table 5.3 REJ Monthly Electricity Utility Billing Data for 2004

Utility Bulling Date					Consumption		Demand	Tdb (F)
Month	Day	Year	date	Days/ Mo	(kWh/Mo)	(kWh/day)	(kW/Mo)	
Jan	30	2004	01/30/04	30	680,000	22,667	1260.0	54.01
Feb	27	2004	02/27/04	28	616,000	22,000	1180.0	50.92
Mar	31	2004	03/31/04	33	740,000	22,424	1240.0	65.31
Apr	30	2004	04/30/04	30	718,000	23,933	1280.0	67.65
May	28	2004	05/28/04	28	692,000	24,714	1280.0	74.17
Jun	30	2004	06/30/04	33	822,000	24,909	1280.0	78.90
Jul	30	2004	07/30/04	30	772,000	25,733	1340.0	81.68
Aug	2	2004	09/02/04	34	864,000	25,412	1340.0	81.85
Sep	1	2004	10/01/04	29	704,000	24,276	1340.0	79.12
Oct	1	2004	11/01/04	31	784,000	25,290	1300.0	73.80
Nov	1	2004	12/01/04	30	688,000	22,933	1240.0	60.24
Dec	4	2004	01/04/05	34	706,000	20,765	1240.0	54.23

Figure 5.3 and Figure *5.4* show the electricity use and demand against dry-bulb temperature for the years 2001 and 2004, respectively. It was found that 2001 whole-building electricity and demand were

reduced slightly when compared to 2004 due to operation changes, which are described in Sections 5.2, 5.3, and 5.4.

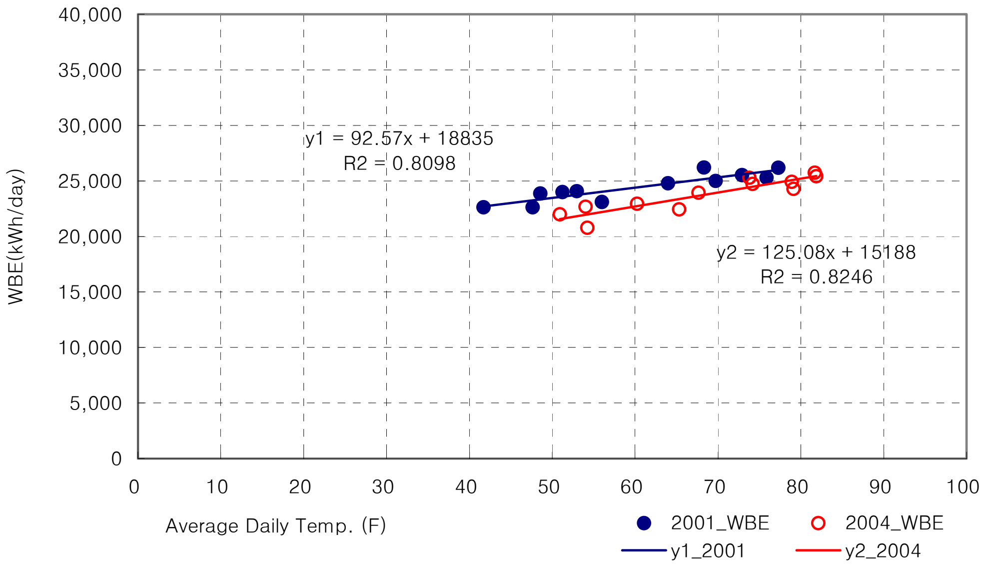


Figure 5.3 *Comparison of 2001 and 2004 whole-building electricity (WBE) against dry-bulb temperature.*

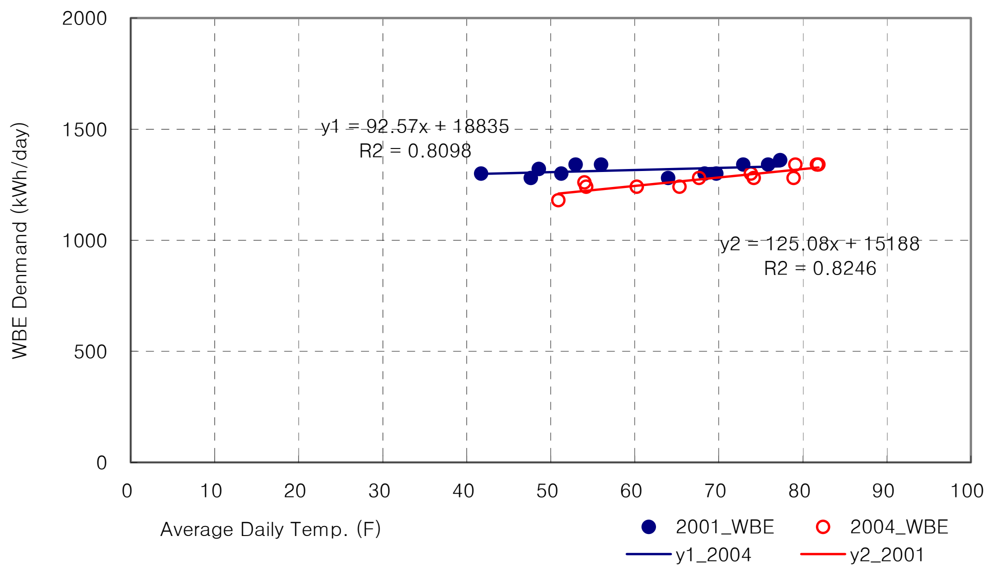


Figure 5.4 *Comparison of 2001 and 2004 demand electricity use against dry-bulb temperature.*

5.1.2 Natural Gas

Figure 5.5 shows the monthly natural gas usage from the case-study building for 2001, 2003, and 2004. Although several data were missed for the entire billing period, natural gas usage was relatively constant with average gas usage of 18, 120 CCF/ month, except for December and January.

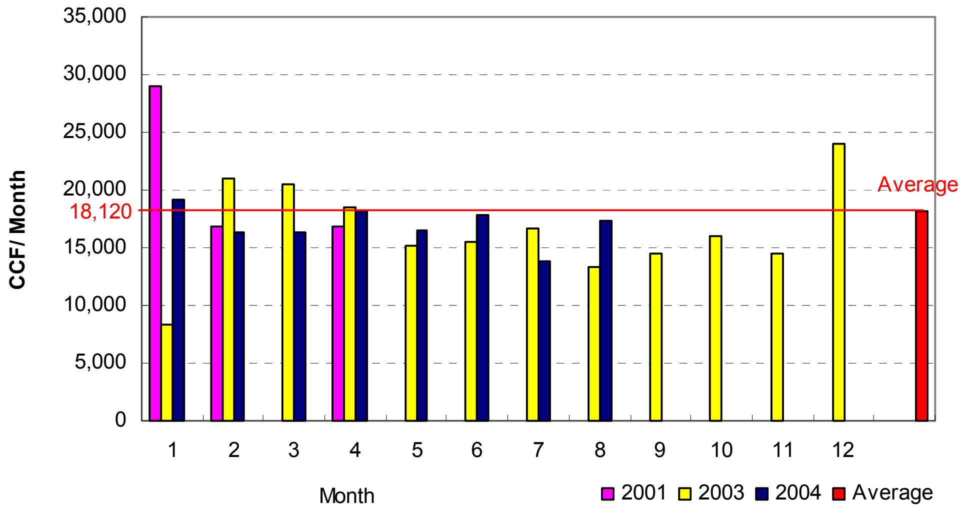


Figure 5.5 *Comparison of REJ monthly gas utility billing data from 2001 to 2004.*

5.2 Whole-building Energy Use

Measured data from the whole-building energy metering as described in Chapter IV, Section 4.4 were analyzed to verify as-built building energy performance and operations for the years 2001 and 2004, in terms of whole-building electricity use, motor control center (MCC) electricity use, lighting and receptacles (WBE-MCC) electricity use, cooling energy use, and heating energy use.

5.2.1 Whole-building Electricity Use

Figure 5.6 shows the time series plot of the 2001 and 2004 measured whole-building electricity (WBE) use with residual, while Figure 5.7 shows the x-y scatter plot of the 2001 and 2004 measured whole-building electricity (WBE) use against dry-bulb temperature with weekend and weekday use. As indicated with a box in Figure 5.6, it can be observed that the 2004 WBE was reduced for the period from

January to July when compared to 2001, due to a reduction of the MCC electricity, which is analyzed in the following Section 5.2.2.

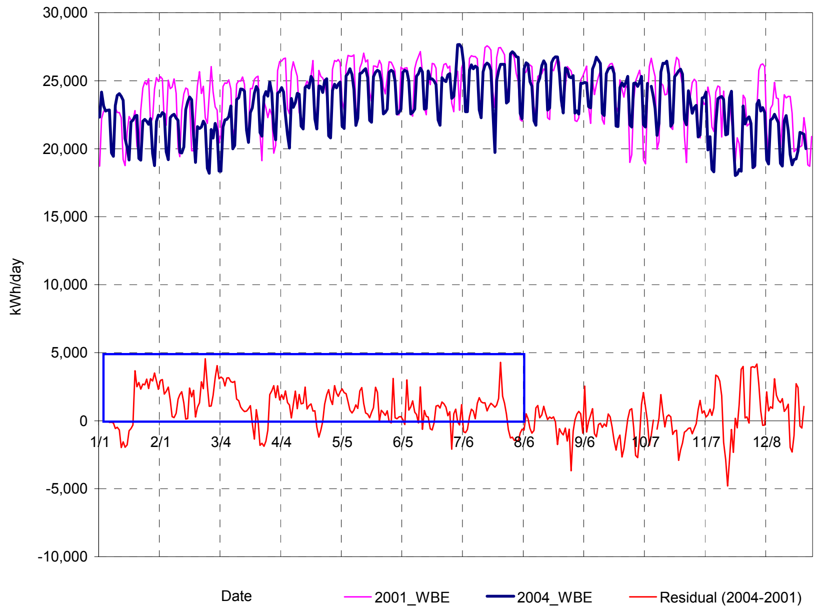


Figure 5.6 *Time series plot of 2001 and 2004 measured daily whole-building electricity and residual.*

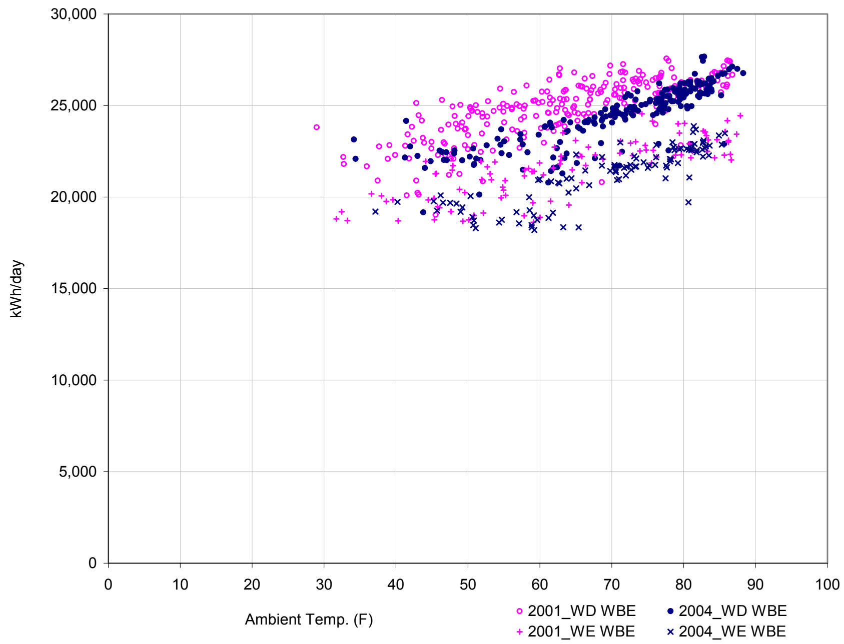


Figure 5.7 *X-Y Scatter plot of 2001 and 2004 measured daily whole-building electricity against DB.*

5.2.2 Motor Control Center (MCC) Electricity Use

As shown in Figure 5.8, the Motor Control Center (MCC) electricity use for 2001 was almost the same as 2004 during the normal operation period from May to August. However, the MCC electricity fluctuated significantly during the part load periods, depending on chiller operation as analyzed in Section 5.3. Figure 5.9 shows that 2004 MCC electricity decreased below 70 ^{o}F when compared to 2001.

5.2.3 Lighting and Receptacle (WBE-MCC) Electricity Use

Whole-building lighting and receptacle (L&R) electricity use was calculated in this study by subtracting motor control center (MCC) electricity from whole-building electricity. As shown in Figure 5.10, the 2001 lighting and receptacle electricity decreased slightly when compared to 2004 for the entire period. Figure 5.11 shows the lighting and receptacle electricity with two groups for weekday and weekend, which have a slight decrease in use with increasing temperature.

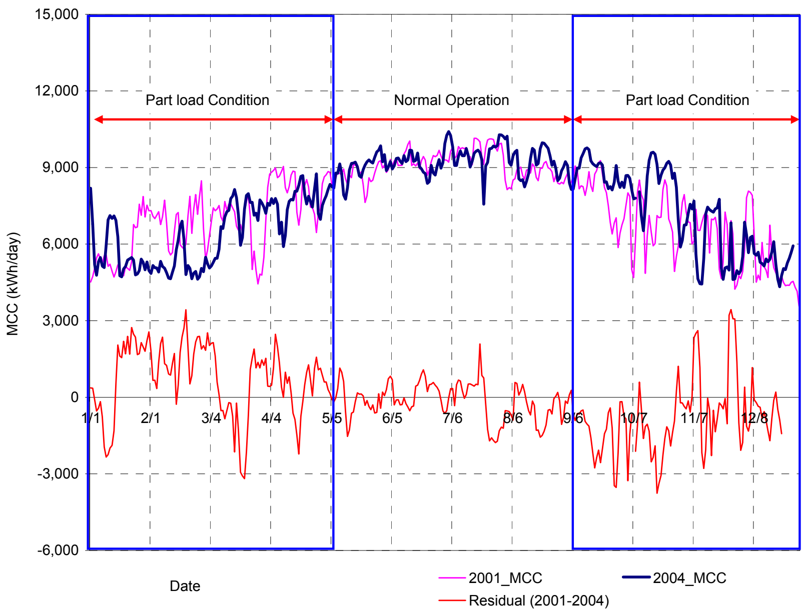


Figure 5.8 *Time series plot of 2001 and 2004 measured daily Motor Control Center (MCC) electricity use and residual.*

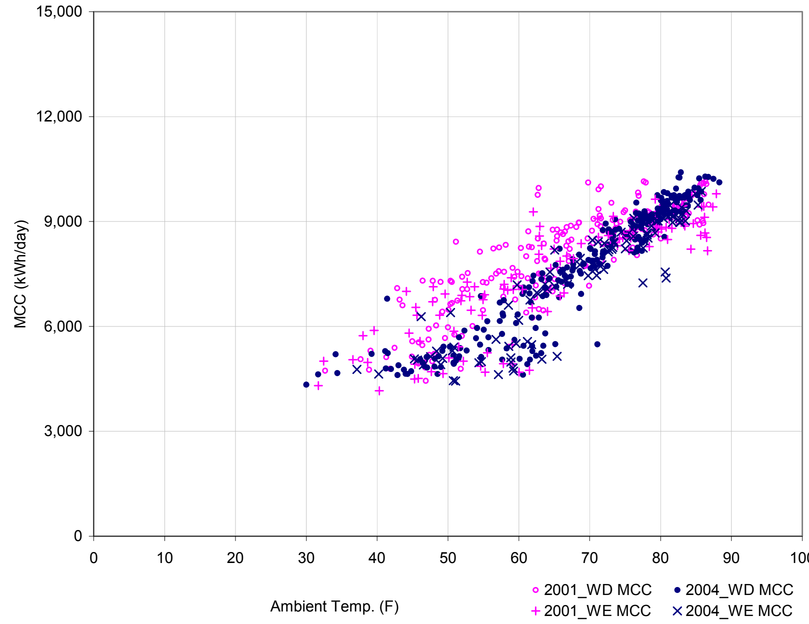


Figure 5.9 *X-Y scatter plot of 2001 and 2004 measured daily Motor Control Center (MCC) electricity use against dry-bulb temperature.*

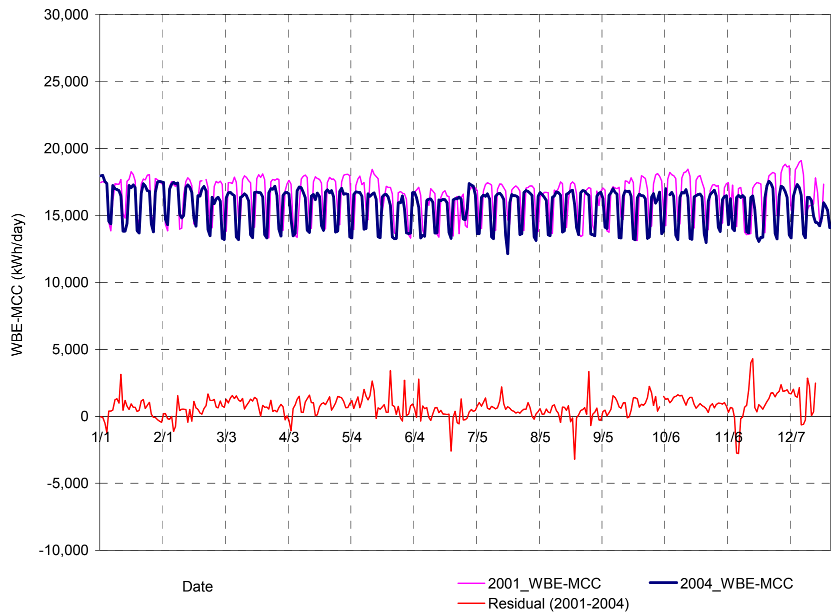


Figure 5.10 *Time series plot of 2001 and 2004 measured daily WBE-MCC (L&R) and residual.*

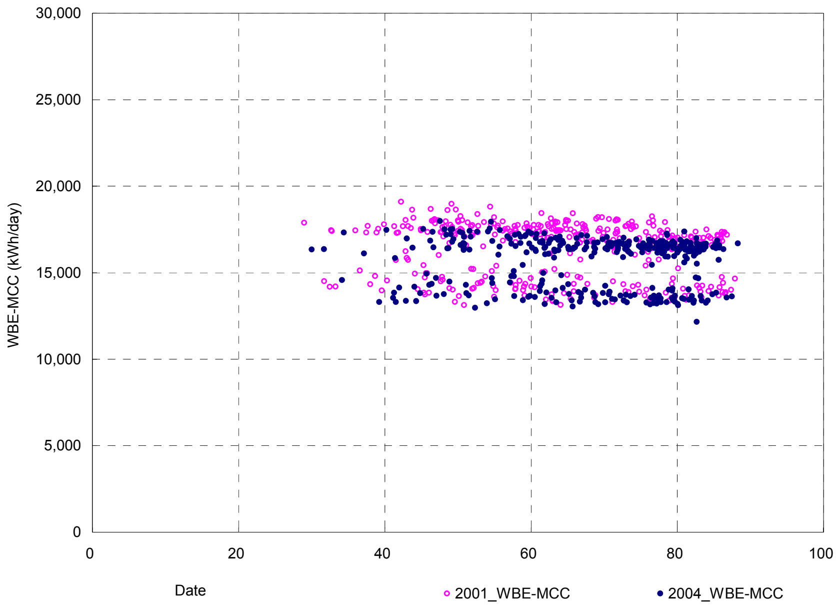


Figure 5.11 *X-Y scatter plot of 2001 and 2004 measured daily WBE-MCC (L&R) against dry-bulb temperature.*

5.2.4 Heating Energy Use

Figure 5.12 shows a time series plot of the 2001 measured heating energy use, along with dry-bulb temperature. In this figure, the heating energy use suddenly dropped on August 1st even though dry-bulb temperature was relatively similar to the previous period due to operation change. Figure 5.13 shows the x-y scatter plot of the 2001 measured heating energy use against dry-bulb temperature for the two periods before and after operation change. Figure 5.14 shows the time series comparison of the 2001 and 2004 heating energy use, while Figure 5.15 shows the x-y scatter plot of the 2001 and 2004 heating energy use against dry-bulb temperature. In 2004, the heating energy use was almost constant regardless of dry-bulb temperature, which was similar to the 2001 heating energy use after operation change.

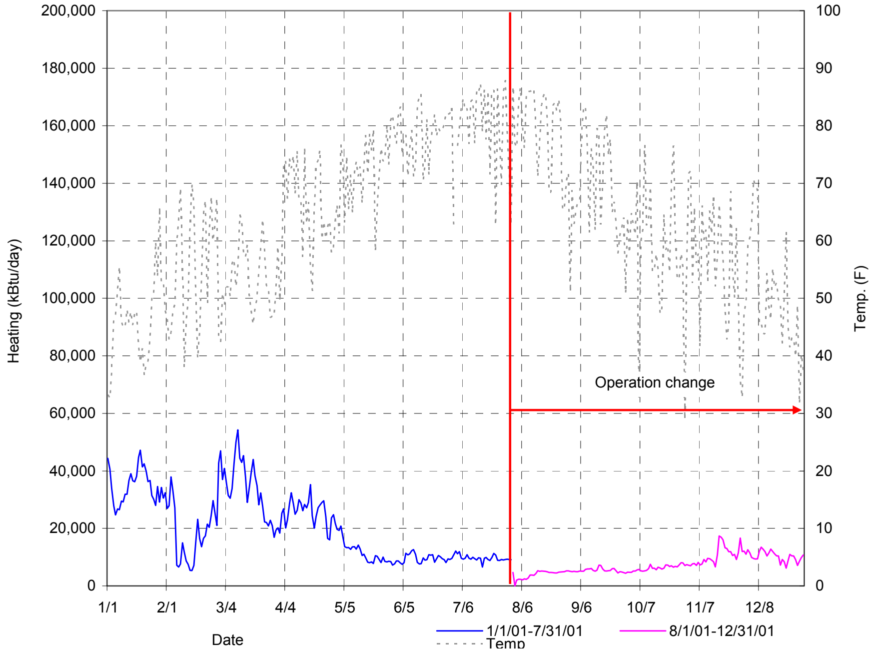


Figure 5.12 *Time series plot of 2001 measured daily heating energy use against dry-bulb temperature before and after operational change.*

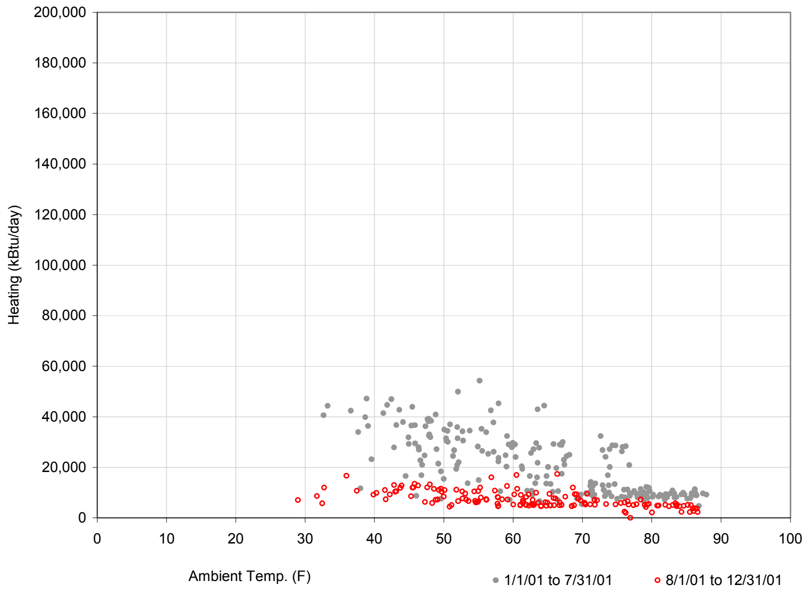


Figure 5.13 *X-Y scatter plot of 2001 measured daily heating energy use against dry-bulb temperature before and after operational change.*

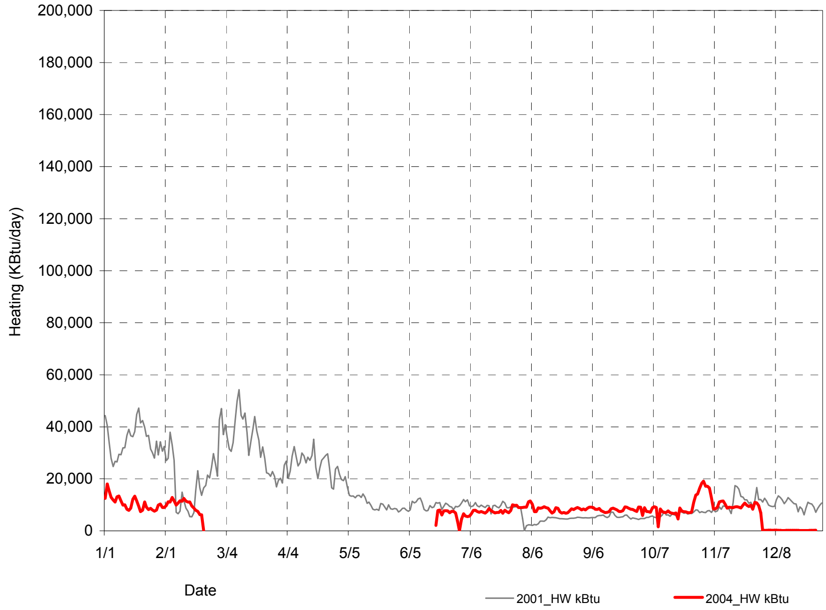


Figure 5.14 *Time series plot of 2001 and 2004 measured daily heating energy use.*

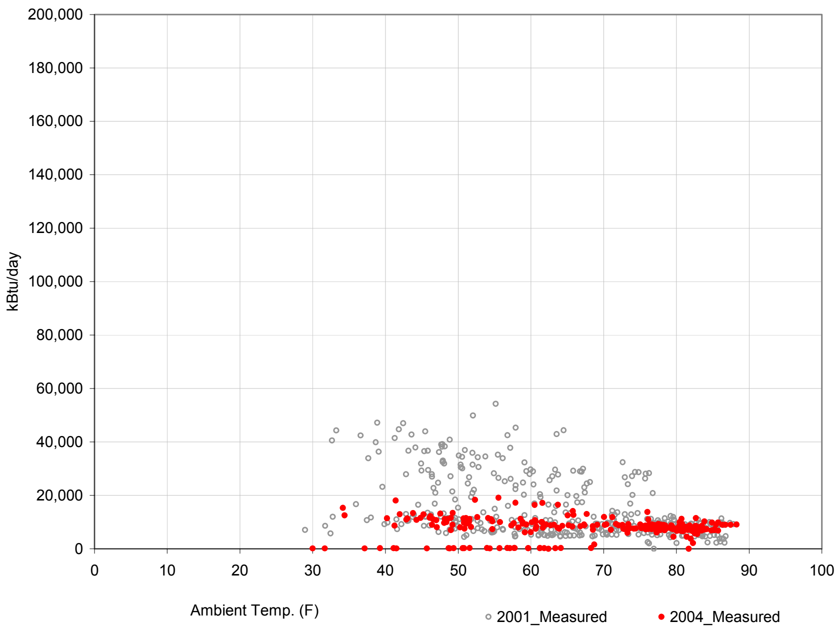


Figure 5.15 *X-Y scatter plot of 2001 and 2004 measured daily heating energy use against dry-bulb temperature.*

5.2.5 Cooling Energy Use

Figure 5.16 shows the time series plot of the 2001 measured cooling energy use, along with dry-bulb temperature. In this figure, cooling energy use suddenly dropped at the same time as the heating energy drop on August 1st due to heating operation change as described previously in Section 5.2.4. Figure 5.17 shows the x-y scatter plot of the 2001 measured cooling energy use against dry-bulb temperature during the two periods before and after heating operation change. Cooling energy consumption was also decreased for the period after heating operation change.

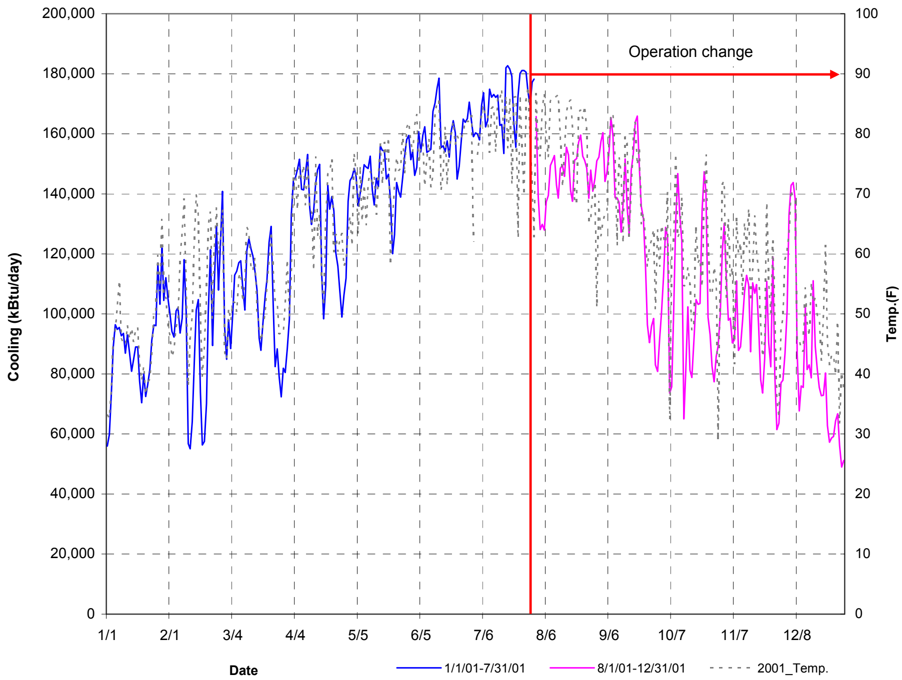


Figure 5.16 *Time series plot of 2001 measured daily cooling energy use against dry-bulb temperature before and after operational change.*

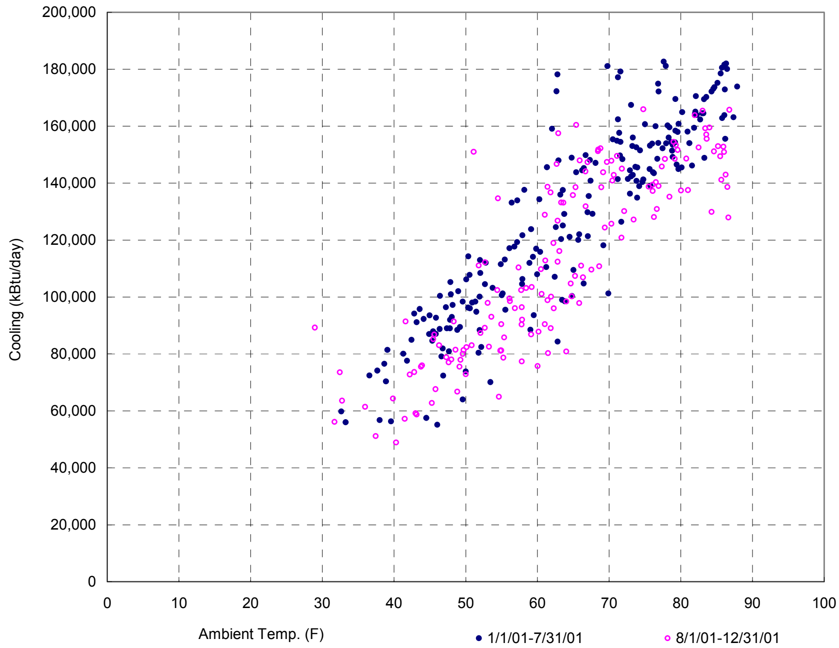


Figure 5.17 *X-Y scatter plot of 2001 measured daily cooling energy use against dry-bulb temperature before and after operation change.*

As described in Chapter 4, Section 4.4.1, a new chiller was added in 2003 to the building and this chiller was running instead of one of the two existing chillers. However, no additional sensors were installed to measure chiller water flow and supply and return temperatures, which are necessary for calculating the third chiller's cooling energy production. Therefore, the total cooling energy use for 2004 was synthesized based on a correlation of the Motor Control Center (MCC) electricity use that included total chiller electricity use, using the 4P change-point regression model as described in Chapter 4, Section 4.3.2. The synthesized cooling energy use was verified with measured 2001 cooling energy use as shown in Figure 5.18. Figure 5.19 shows the 2004 predicted cooling energy compared to the 2001 measured cooling use against the dry-bulb temperature. This synthesized 2004 cooling energy use was used to calibrate the DOE-2 simulation.

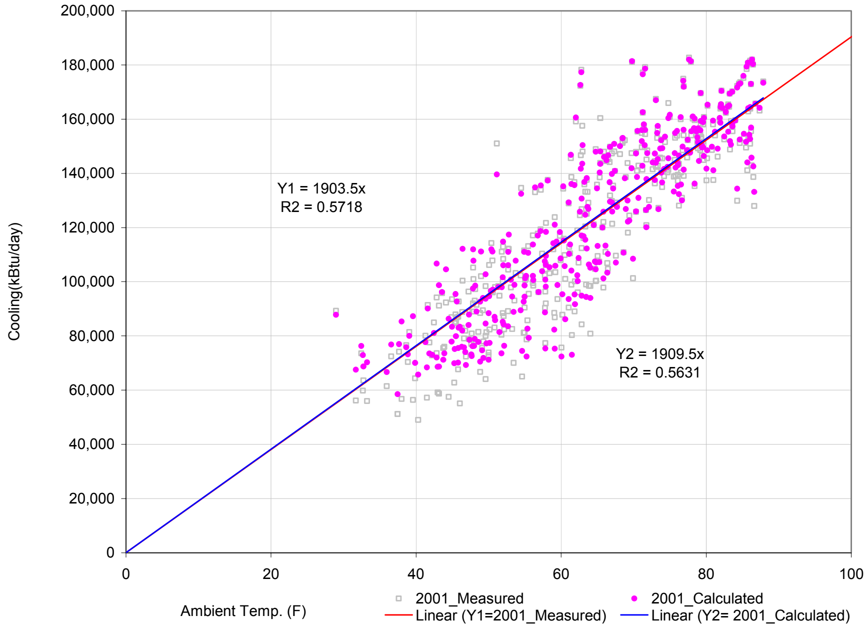


Figure 5.18 *X-Y scatter plot of 2001 measured and calculated daily cooling energy use against dry-bulb temperature.*

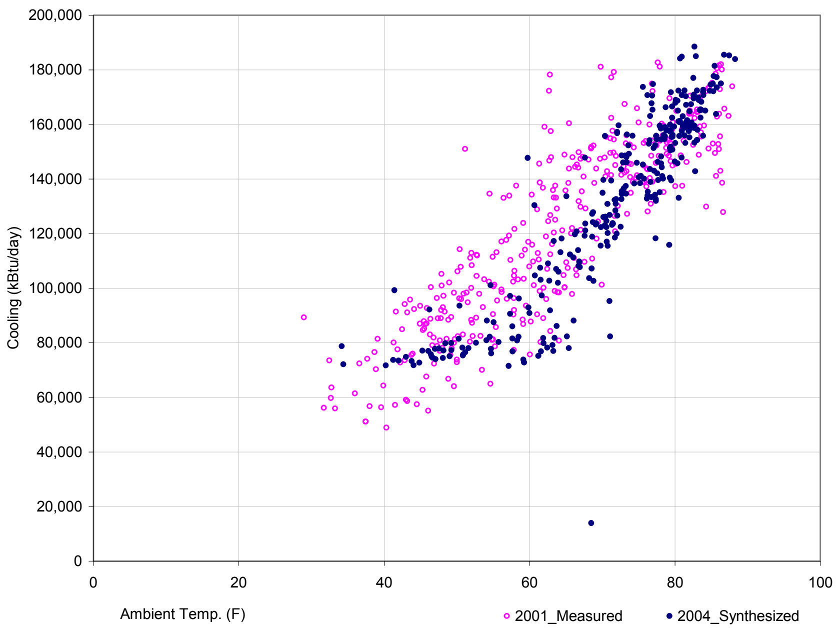


Figure 5.19 *X-Y scatter plot of 2001 measured and 2004 calculated daily cooling energy use against dry-bulb temperature.*

5.3 Chiller Performance

For the measurement and verification of chiller performance, the chiller efficiency (kW/ton) was analyzed as a function of the chiller load for each chiller, based on the monitoring data as described in Chapter IV, Section 4.4. The measured chiller efficiency was first compared to the manufacturer's data as shown in Table 5.4, and then analyzed according to the parallel and sequence chiller operation mode. As shown in Figure 5.20, the measured individual chiller efficiency was lower than the manufacturer's data at part-load conditions below 300 tons. In Figure 5.21, it is shown that a parallel operation of two chillers was less efficient than the sequenced operation at part-load condition below 400 tons. Therefore, it is recommended that the chiller start only after the lead chiller exceeds its optimum loading point of 400 tons, which is about 86% of maximum load for each chiller (465 ton). In this study, the measured chiller efficiency at full loads was incorporated into the as-built DOE-2 simulation for the case-study building. For part-load condition, the DOE-2 default curve was used because the measured data curve was found not to be very different from the DOE-2 default curve as described in Chapter 4, Section 4.5.6. However, switching chiller performance curve needs to be developed to account for actual operation with parallel or sequence operation at part-load conditions as described in Chapter IV, Section 4.5.6.

Table 5.4 Performance Test Results by TRANE Manufacturer

Percent	Tons	Evaporator (^oF)		Condenser (^oF)		kW	kW/ton
		Leaving Temperature	Entering Temperature	Entering Temperature	Leaving Temperature		
100	465	45	60.0	85.0	94.3	253	0.544
90	419	45	58.5	82.5	90.8	212	0.507
80	372	45	57.0	80.0	87.3	183	0.492
70	326	45	55.5	77.5	83.9	157	0.482
60	279	45	54.0	75.0	80.5	132	0.473
50	233	45	52.5	72.5	77.1	112	0.482
40	186	45	51.0	70.0	73.7	93	0.500
30	140	45	49.5	67.5	70.3	76	0.545
20	93	45	48.0	65.0	66.9	58	0.624
15	70	45	47.3	63.8	65.2	49	0.703

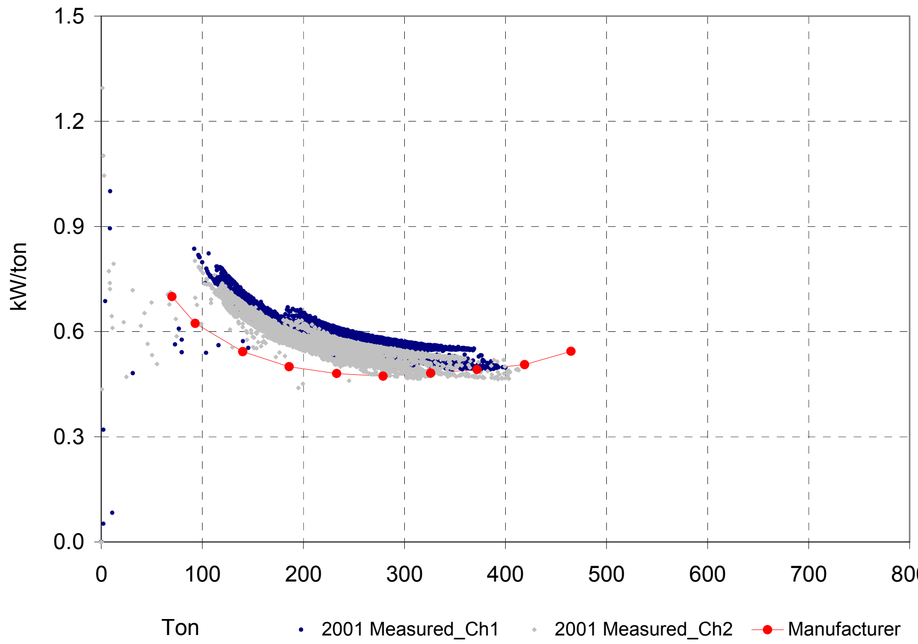


Figure 5.20 *2001 measured individual chiller efficiency (kW/ton) against cooling loads (ton).*

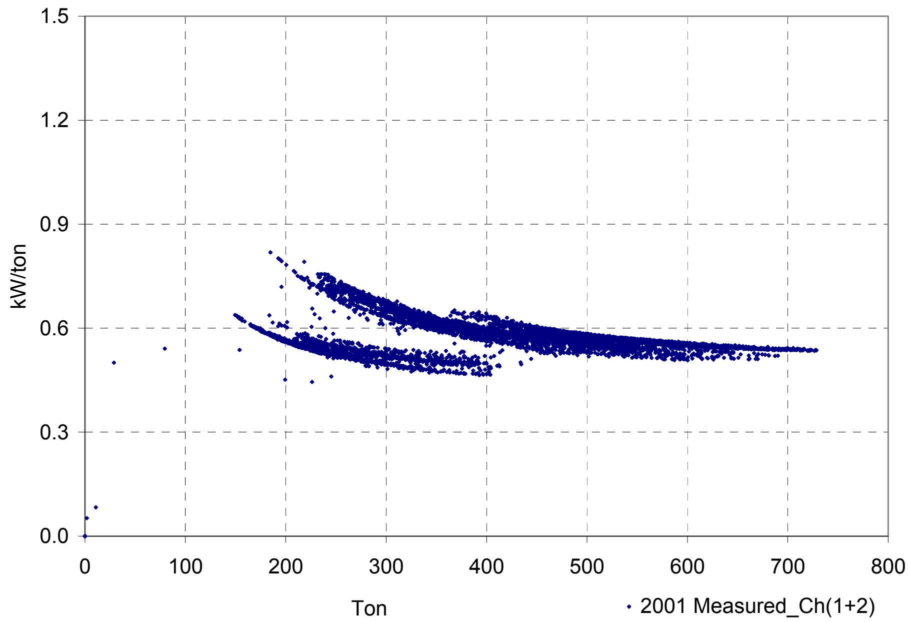


Figure 5.21 *2001 measured total chiller (1+2) efficiency (kW/ton) against cooling loads (ton).*

5.4 Typical AHU (DDVAV) Operation

Several temperature and RH points were measured to verify the actual operation and condition for a typical air handling unit (AHU) located on the 4th floor of the case-study building, using portable data loggers as described in Chapter IV, Section 4.4.2, including: hot deck, cold deck, and supply and return air temperature. As shown in Figure 5.22, the hot and cold deck temperatures were grouped according to the operation periods. The hot deck temperature was between 85 ^oF and 95 ^oF during the first period and was between 70 ^oF and 80 ^oF for the second period. Cold deck air temperature was also changed from about 55 ^oF to 50 ^oF for the period before and after operation change. In Figure 5.22, it was also shown that the hot deck and cold deck air temperatures were almost constant due to no outside air reset control. As shown in Figure 5.23, the mixed air temperature was also grouped according to operation periods, but almost constant because outside air was pre-conditioned before it reached the mixing air chamber. Supply air temperature was shown to be between a minimum of 55 ^oF to a maximum of 75 ^oF for both south and north zones as shown in Figure 5.24 and Figure 5.26. Return air temperature was almost constant for both south and north zone as shown in Figure 5.25 and Figure 5.27. In this study, the measured data were incorporated into the DOE-2 simulation to calibrate the as-built simulation model, which is discussed in Chapter VI, Sections 6.2 and 6.3.

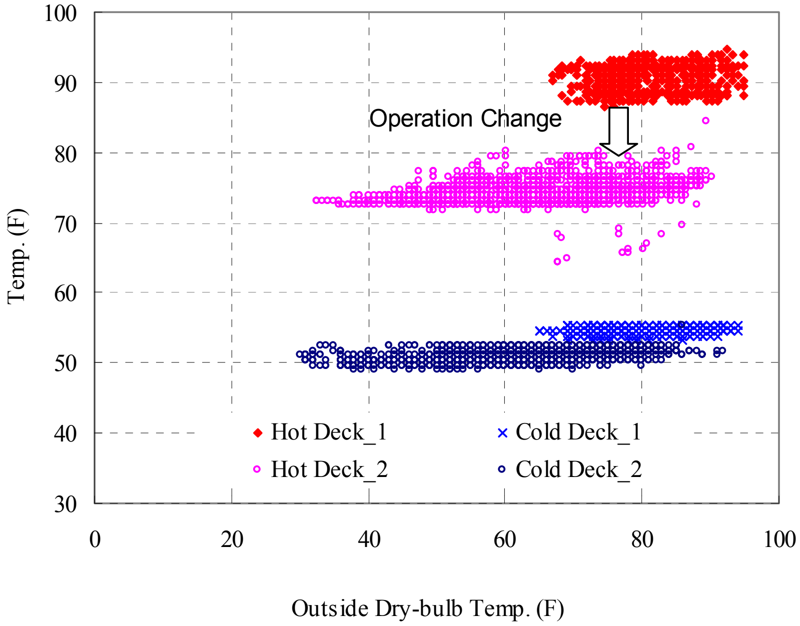


Figure 5.22 *Hot and cold deck air temperatures against outdoor dry-bulb temperature of the 4th floor east AHU(DDVAV).*

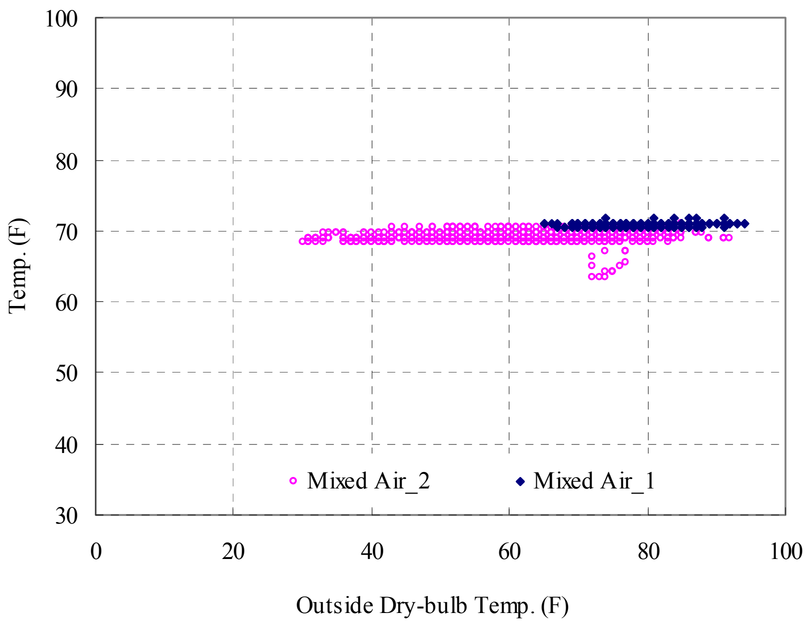


Figure 5.23 *Mixed air temperature against outdoor dry-bulb temperature of the 4th floor east AHU(DDVAV).*

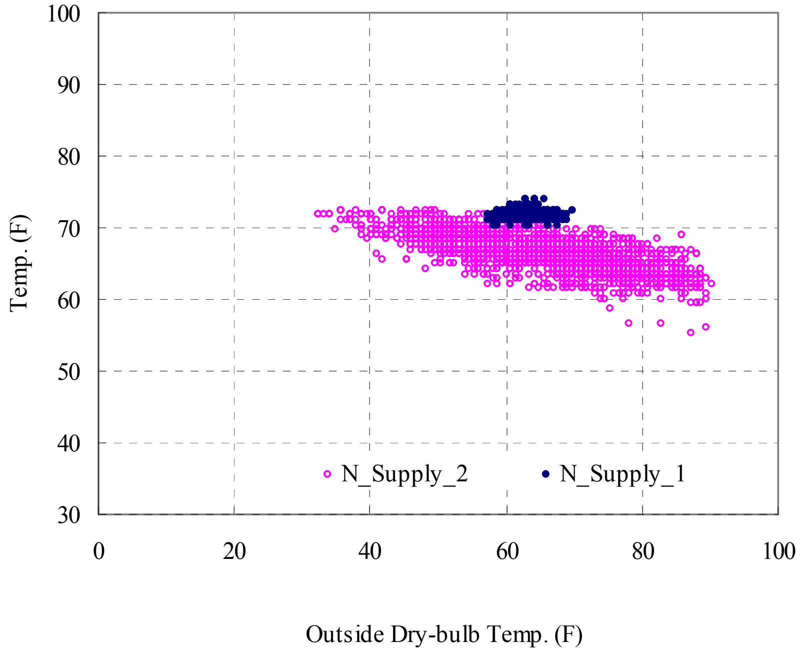


Figure 5.24 *North zone supply air temperature against outdoor dry-bulb temperature of the 4th floor east AHU(DDVAV).*

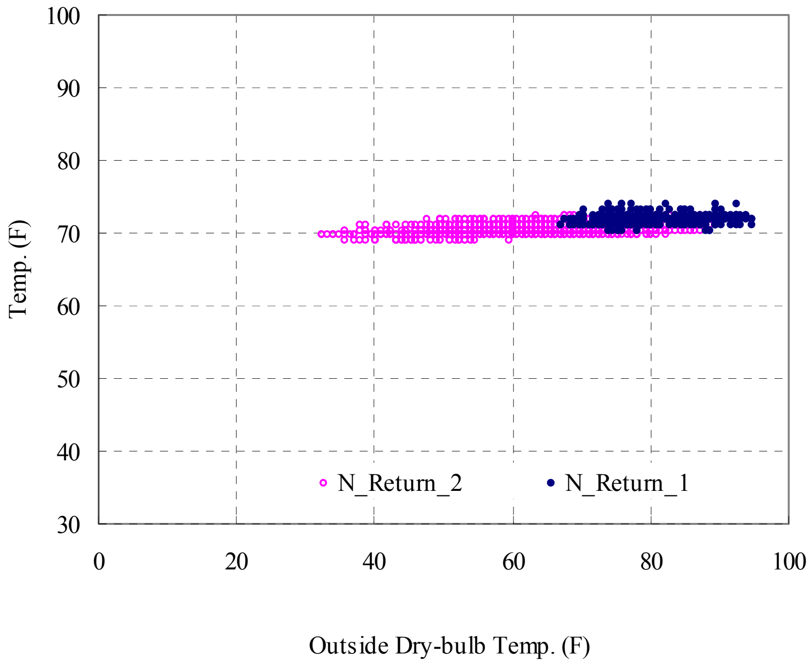


Figure 5.25 *North zone return air temperature against outdoor dry-bulb temperature of the 4th floor east AHU(DDVAV).*

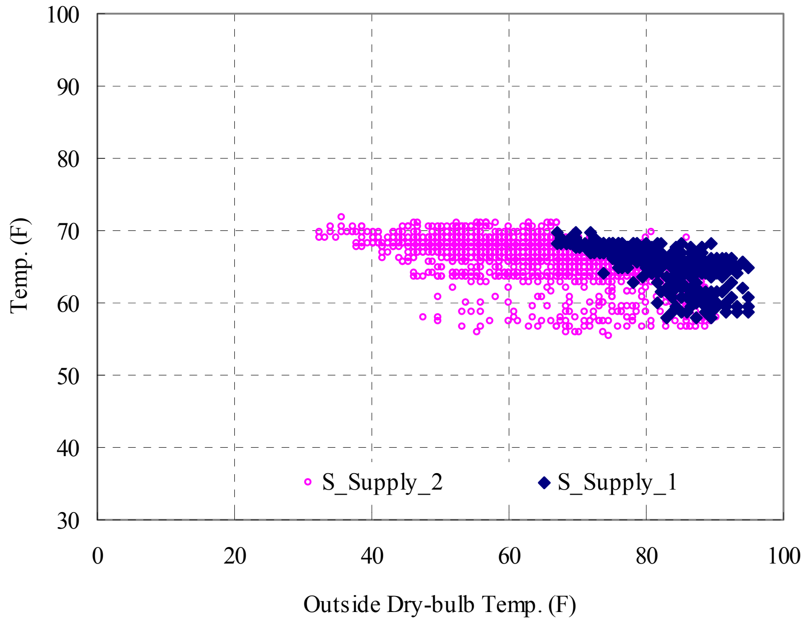


Figure 5.26 *South zone supply air **t**emperature against outdoor dry-bulb temperature of the 4th floor east AHU(DDVAV).*

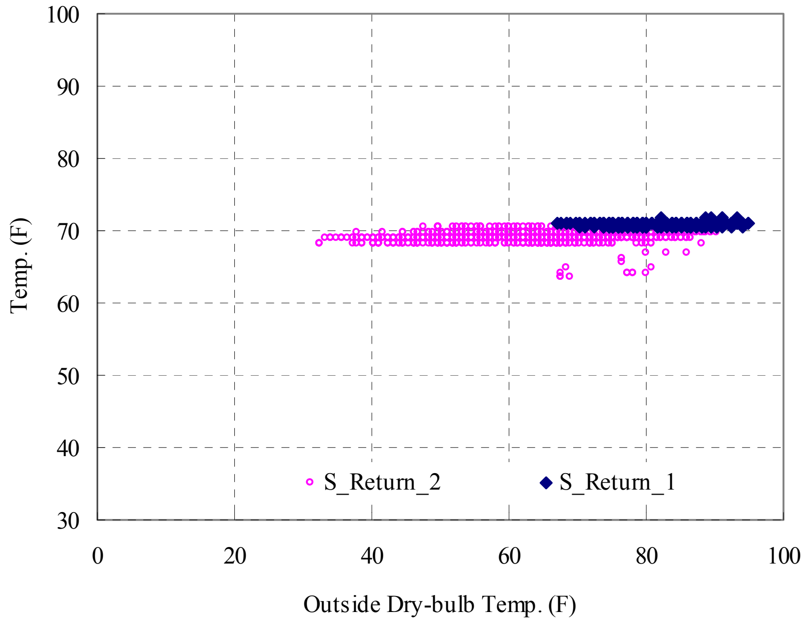


Figure 5.27 *South zone return air temperature against outdoor dry-bulb temperature of the 4th floor east AHU(DDVAV).*

5.5 Solar Transmittance of Low-e Glazing

Solar transmittance of sample glazing was measured using two types of pyranometers such as Eppley Precision Pyranometer (PSP) and a Li-Cor Pyranometer as described in Chapter IV, Section 4.4.3. Table 5.5 shows the measured solar transmittance by PSP and Li-Cor compared to the glazing library generated by the Window 5 program. The solar transmittance measured by the Eppley PSP shows up to a 27.72% increase when compared to Window 5.2, while that by the Li-Cor shows up to a 4.25% increase.

Table 5.5 Solar Transmittance measured by PSP and Li-Cor and generated from Window 5

Types	Sensors	Solar Transmittance (Average)		Increase (%)
		20-30 degree	30-40 degree	
Single Glazing (Clear_3DAT)	PSP	-	0.851	3.37
	Li-Cor	-	0.818	-0.62
	Window 5.2	-	0.823	0.00
Double Glazing	PSP	-	0.731	6.78
	Li-Cor	-	0.682	-0.44
	Window 5.2	-	0.685	0.00
Low-e (Upper) (VE1-2M)	PSP	0.407	-	27.72
	Li-Cor	0.316	-	-1.00
	Window 5.2	0.319	-	0.00
Low-e (Lower) (VE1-40#2)	PSP	0.256	-	26.20
	LiCor	0.212	-	4.25
	Window 5.2	0.203	-	0.00

Figure 5.28 illustrates a three-way comparison of the solar transmittance against incidence angle from the Eppley PSP, the Li-Cor, and the Window 5.2 program. Due to the shading from the test box, bad data above a 70 degree angle of incidence were cleaned. In general, a PSP is mainly used as a standard to calibrate other parameters due to its high accuracy with a typical error of 1% (Campbell Scientific 1991) rather than a Li-Cor that has a typical error of 5% (Li-COR 1991). However, the three-way comparison shows that the solar transmittance measured by Li-Cor was closer to that of Window 5 rather than that from the PSP. Consequently, it is assumed that the Eppley PSP in the test box was affected by the heat generated in the test box because the Eppley PSP is a thermopile-based pyranometer, while the Li-Cor is a solar cell-based pyranometer, which doesn't respond to the solar spectrum wavelengths over 1.1 μ or under 0.4 μ.

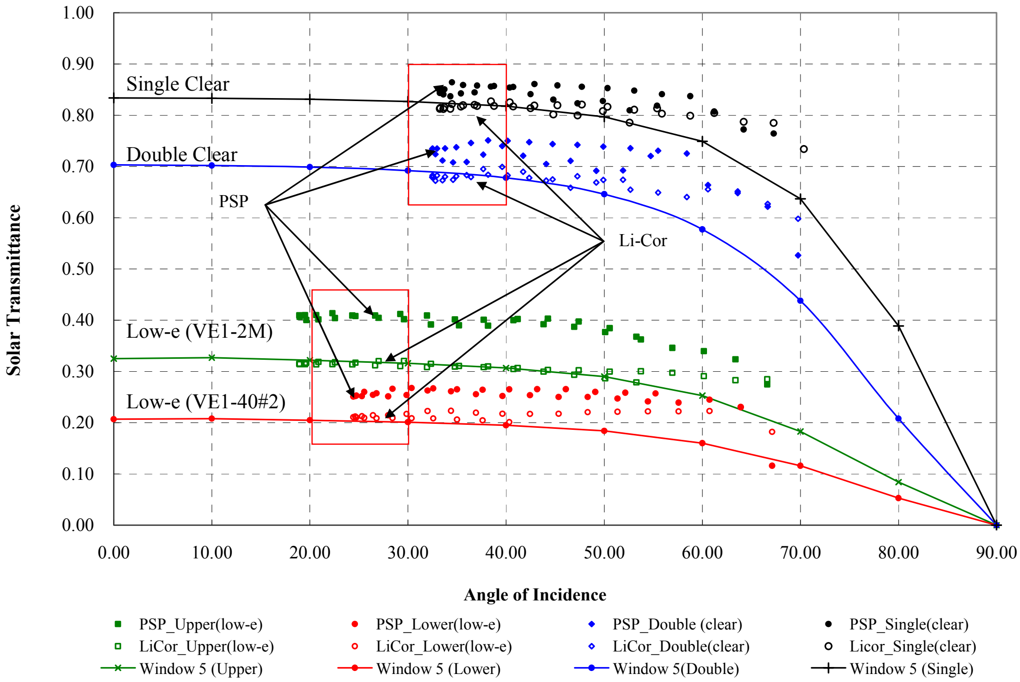


Figure 5.28 *Measured vs. Window 5.2 solar transmittance against angle of incidence.*
(Note: Due to the shading from the test box, bad data above a 70 degree angle of incidence were cleaned.)

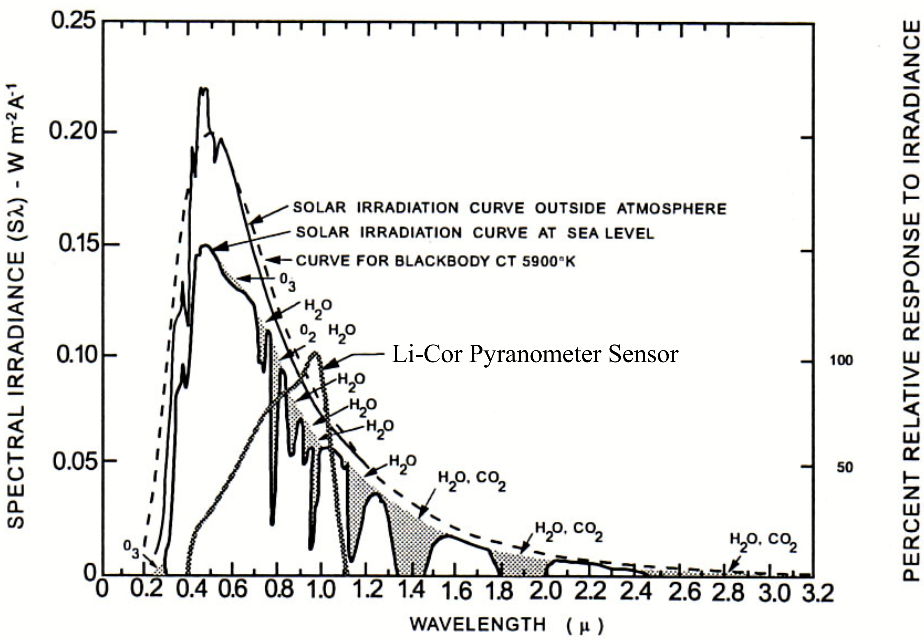


Figure 5.29 *Li-200SA Pyranometer spectral response.*
(Reprinted with permission from LI-COR Biosciences)

5.6 Summary of Measured Data

Measured data from the case-study building were analyzed to verify as-built building energy performance and operations for the years 2001 and 2004, including: utility billing data, whole-building energy use, and component performance such as such as chiller efficiency, typical AHU operation, and solar transmittance of low-e glazing. From the monthly utility billing analysis, it was identified that the case-study building has started to operate normally since 2001. Measured data were also verified with monthly utility data for 2001 and 2004. Measured data from the whole-building energy metering were analyzed, including: whole-building electricity use, motor control center (MCC) electricity use, lighting and receptacle (WBE-MCC) electricity use, and cooling and heating energy use. In 2004, a new chiller was added to the case-study building. Therefore, the 2004 cooling energy use was synthesized based on a correlation with MCC electricity use including total chiller electricity use. The measured chiller efficiency was first compared to the manufacturer's data and then analyzed according to the parallel and sequence chiller operation mode. The measured chiller efficiency at full loads was incorporated into the as-built DOE-2 simulation for the case-study building. For part-load conditions, the DOE-2 default curve was used because the measured data curve was found not to be very different from the DOE-2 default curve. Several temperature and RH points were measured to verify the actual operation and condition for a typical air handling unit (AHU) located on the 4th floor of the case-study building, using portable data, including: hot deck, cold deck, and supply and return air temperatures. The hot deck and cold deck temperatures were grouped according to the operation periods. The hot deck temperature and cold deck air temperature were changed for the period before and after operation change. In this study, the measured data were incorporated into the DOE-2 simulation to calibrate the as-built simulation model. A three-way comparison of the solar transmittance against incidence angle was performed using the data from the Eppley PSP, the Li-Cor, and the Window 5.2 program. The three-way comparison shows that the solar transmittance measured by Li-Cor was closer to that of Window 5 rather than that from the PSP.

CHAPTER VI

RESULTS: AS-BUILT SIMULATION AND CALIBRATION OF THE CASE- STUDY BUILDING

This chapter describes the as-built simulation models and calibration of the models to data from the case-study building, the Robert E. Johnson (REJ) state office building in Austin, Texas. To accomplish this, three different as-built simulation models were developed in this study as defined in Table 6.1. The 2001 as-built model was first developed based on as-built design conditions, and then it was calibrated with 2001 measured data for evaluating energy performance compared to the energy baselines as discussed in Chapter IV, Section 4.3. The 2004 calibrated as-built model was also developed to evaluate the potential energy savings from the improvements that were proposed in Chapter VIII. Then, a detailed simulation and calibration was performed based on the methods described in Chapter IV, Section 4.5. The following Sections discuss in detail the as-built model simulations and the calibration results for the 2001 as-built model, the 2001 calibrated as-built model, and the 2004 calibrated as-built model, respectively.

6.1 As-built Simulation Model

This Section describes the 2001 as-built simulation model based on the information from site visits, as-built drawings, and measured data. Certain assumptions were also applied to the DOE-2 simulation model due to the limitations of the DOE-2.1e simulation program and insufficient sub-metered data. Detailed models are described in the following Sections, in terms of DOE-2 building LOADS, SYSTEMS, and PLANT.

6.1.1 Building LOADS

Building loads are described in terms of building location, construction and materials, window properties, and space zoning and conditions.

Table 6.1 2001 and 2004 As-built Model Description for the REJ Building

Models	Model Definition	Model Descriptions	Data Source and Calibration Methods
2001 As-built Model	As-built design conditions with DOE-2 default values.	1. Measured weather data, 2. As-built design conditions, including: building shape, construction and materials, space zoning, and HVAC&R systems. 3. Measured lighting and equipment loads and schedules, and 4. Assumption with DOE-2 defaults.	1. 2001 measured weather data, 2. Site visits, 3. As-built drawings, 4. DOE-2 manual, and 5. Measured typical lighting and receptacle schedule (ASHRAE RP-1093).
2001 Calibrated As-built Model	The same as 2001 as-built model, but calibrated with measured data.	1. Included the 2001 as-built model conditions, 2. Adjusted lighting and equipment loads and schedule, 3. Adjusted HVAC&R system's performance and operation changes, and 4. Adjusted other calibration factors.	1. Included the 2001 as-built model data source, 2. 2001 measured energy data, 3. EMCS data, 4. Interview with building Operator, and 5 Signature method for model calibration.
2004 Calibrated As-built Model	The same as 2001 calibrated as-built model, but calibrated with 2004 measured data.	1. Included the 2001 calibrated model conditions, 2. 2004 lighting and equipment loads and schedules, 3. Adjusted 2004 HVAC&R system operation changes, and 4. Adjusted other calibration factors.	1. Included the 2001 calibrated model data source, 2. 2004 measured weather data, 3. 2004 measured energy data, and 4. On-site measurements.

6.1.1.1 Building Location

The building's north facade faces approximately 14 degrees east of north, which exposes the south, west, and north façade to direct sunlight in the late afternoon. The building is divided into three Sections, with the divisions created by the ground level breezeway and vehicular access area as described in Chapter IV, Section 4.1.1. Table 6.2 shows information on building location of the case-study building, which is located a few miles away from the NWS weather station (Austin Camp Mabry) in Austin, Texas. Daylight savings time and U.S. holidays were applied to the DOE-2 simulation of the REJ building. Monthly ground temperatures were automatically calculated using the method of Kusuda and Achenbach (1965) by the DOE-2 weather processor (Buhl 1999), based on the packed Austin TRY weather files described in Chapter IV, Section 4.5.2. Using the DrawBDL program (Huang, 1993), the south-west façade and south elevation of the REJ building are illustrated in Figure 6.1 and Figure 6.2, and the north-east façade and north elevation of the REJ building are shown in Figure 6.3 and Figure 6.4. To account for the shading effect from the adjacent trees (i.e., live oaks) and buildings, as shown in Figure 6.1, shading schedules were assumed according to the three different seasons as shown in Table 6.3.

Table 6.2 Building Location of the REJ Building

DOE-2 Keywords	DOE-2 Values	Description
Latitude	30.3	Austin weather station (30.29 N)
Longitude	97.7	Austin weather station (97.74 W)
Altitude	610	Austin weather station (658 ft)
Time zone	6	Central Time Zone
Azimuth	14	14 degree east from the north axis
Daylighting Savings	Yes	Daylight savings time
Holiday	Yes	The U.S Holiday
Ground Temperature	No	Auto calculated by DOE-2 weather processor

Table 6.3 DOE-2 Shading Schedules of the REJ Building

Shadings	DOE-2 Keywords	Periods	Values	Remarks
Trees	SHADING-SCHEDLE	THRU APR 30	0.2	Spring
		THRU SEP 30	0.5	Summer
		THRU DEC 31	0.3	Winter
Adjacent Building	SHADE-SCHEDULE	THRU DEC 31	1	All seasons

6.1.1.2 Building Construction

Table 6.4 shows a summary of each wall type with construction and material properties used in this study. Each material was selected from the DOE-2 material library corresponding to the actual materials in as-built drawing. Inside film resistance was defined using the default value of 0.68 for all the inside wall surfaces.

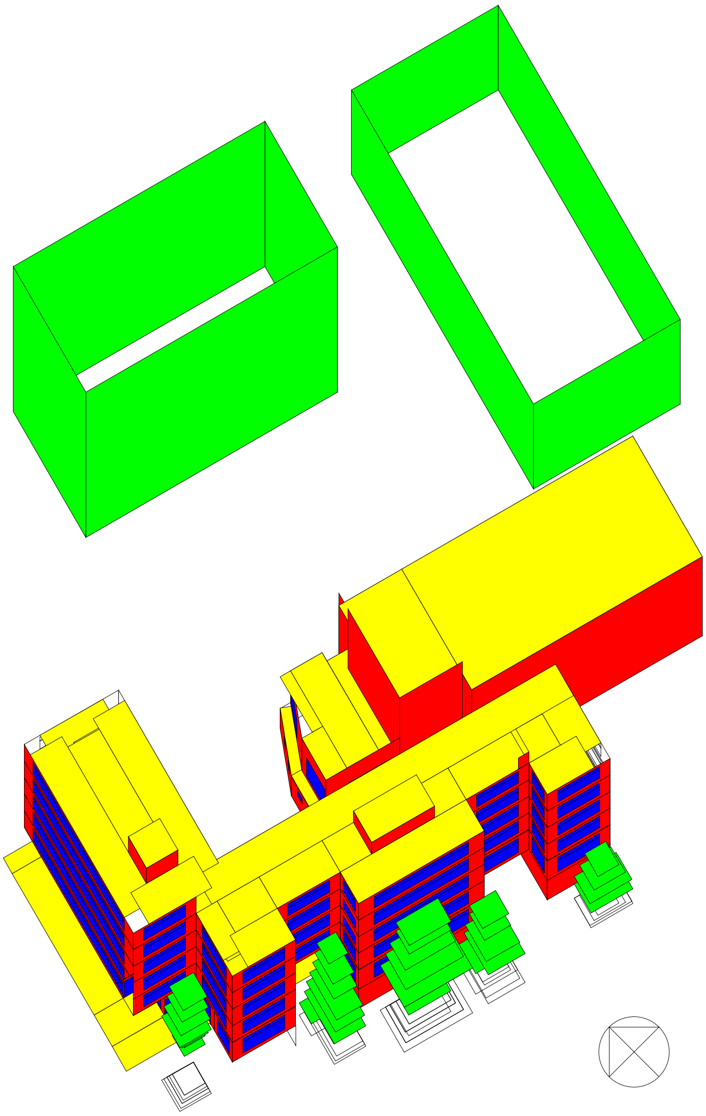


Figure 6.1 *South–west façade of the DOE-2 model using DrawBDL (Huang, 1993).*

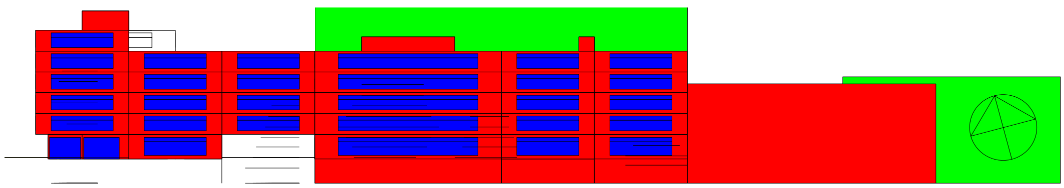


Figure 6.2 *South elevation of the DOE-2 model using DrawBDL (Huang, 1993).*

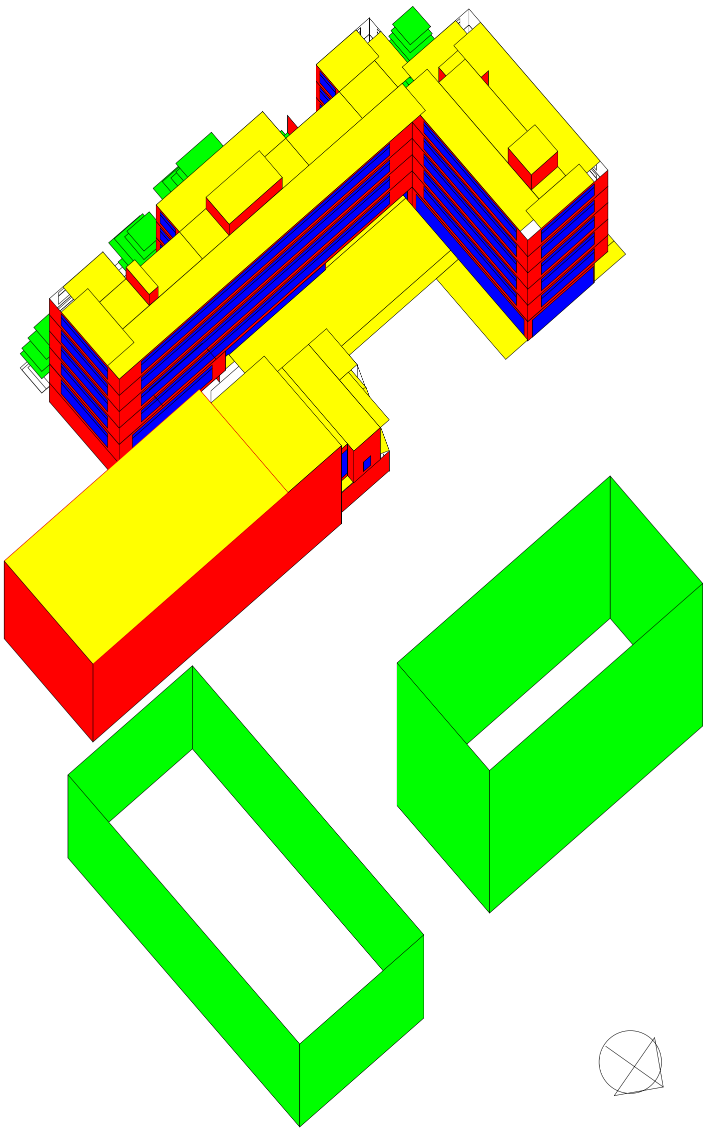


Figure 6.3 *North–east façade of the DOE-2 model using DrawBDL (Huang, 1993).*

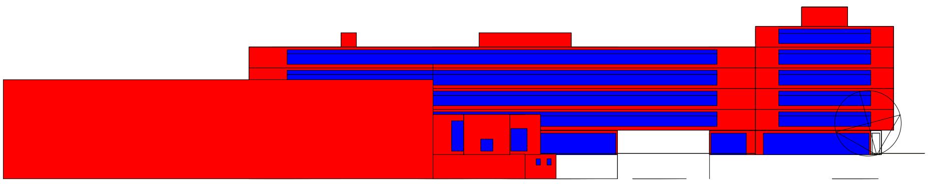


Figure 6.4 *North elevation of the DOE-2 model using DrawBDL (Huang, 1993).*

Table 6.4 Material and Thermal Properties of the Case Study Model

ITEMS	U-NAME			DESCRIPTION	THERMAL PROPERTIES				
	CONSTRUCTION	LAYER	MATERIALS		Thickiness	Conductivity	Density	Specific Heat	Resustance
					Feet	Btu-ft/hr-ft^2-F	lb/ft^3	Btu/lb-F	hr-ft^2-F/Btu
EXTERIOR WALL	WALL-1 (Typical)	EW-1	CC26	Concrete light 80lb	0.6667	0.2083	80	0.2	3.2
			IN02	Batt, R-11	0.2957	0.025	0.6	0.2	11.83
			WMF00	Wall metal frame w/ R-0	-	-	-	-	0.61
			GP02	gypsum 5/8"	0.0521	0.0926	50	0.2	0.56
			Iinside-film-res	0.68	-	-	-	-	-
	WALL-1-2 (Conference Room)	EW-2	WMF00	Wall metal frame w/R-11	-	-	-	-	6
			IN11	fill,3.5" R-11	0.2917	0.027	0.6	0.2	10.8
			Iinside-film-res	0.68	-	-	-	-	-
ROOF	ROOF-1 (Typical)	ROO-1	BR01	Roofing(3/8")	0.0313	0.0939	70	0.35	0.33
			IN03	Batt, R-19	0.5108	0.025	0.6	0.2	20.43
			CC26	Concrete light 80lb	0.6667	0.2083	80	0.2	3.2
			Iinside-film-res	0.68	-	-	-	-	-
	ROOF-2 (Conference Room)	ROO-2	WMF11	Wall metal frame w/R-11	-	-	-	-	6
			IN02	Batt, R-11	0.2957	0.025	0.6	0.2	11.83
			Iinside-film-res	0.68					
UNDERGROUND WALL	WALL-U	UW-1	FIT-1	Fictitious Insulationg Layer	-	-	-	-	17.94
			M-SOL	Earth Soil	1.5	0.5	85	0.2	-
			CC07	Concrete 12"	1				
			IN02	Batt, R-11	0.2957	0.025	0.6	0.2	11.83
			Iinside-film-res	0.68	-	-	-	-	-
UNDERGROUND FLOOR	FLOO-U	UF-1	FIT-2	Fictitious Insulationg Layer	-	-	-	-	1000
			M-SOL	Earth Soil	1.5	0.5	85	0.2	-
			CC07	Concrete 12"	1	0.7576	140	0.2	1.32
			Iinside-film-res	0.68	-	-	-	-	-
INTERIOR FLOOR	FLOOR-1	IF-1	CC36	Concrete 8 "	0.6667	0.0751	30	0.2	8.88
INTERIOR-WALL	WALL-2	I W-1	GP02	Gypsum 5/8"	0.0521	0.0926	50	0.2	0.56
			WMF00	Wall Metal frame w/ R-0	-	-	-	-	0.61
			GP02	Gypsum 5/8"	0.0521	0.0926	50	0.2	0.56
			Iinside-film-res	0.68	-	-	-	-	-
CEILING	CLING-1	CL-1	GP02	Gypsum 5/8"	0.0521	0.0926	50	0.2	0.56
			Iinside-film-res	0.68	-	-	-	-	-

The REJ building is a six-story, 303,389 square foot office building with a basement. Three typical sections, circled in Figure 6.5, are shown in detail in Figure 6.6. The building roof is constructed with high albedo, white roofing and R-20 insulation on a 10" concrete slab as shown in Figure 6.6 (a). The building walls are typically composed of 8"concrete, R-13 batt insulation, metal frame, and 5/8" gypsum board from outside to inside as shown in Figure 6.6 (b). Figure 6.6 (c) shows the underground wall and floor construction, which included 1" of soil with a fictitious layer to account for thermal mass effect in DOE-2 simulation as described in Chapter IV, Section 4.5.4. Table 6.5 shows the calculated U-effective using the methods by Winkelmann (1992) for the underground wall and floor of the case-study building.

Table 6.5 U-Effective for Underground Wall and Floors

Items	Underground Wall Height	Construction	Conduction Factor (F2)	Effective R = A/(F2*Pexp)	Effective U = 1 / Reff	Remarks
Underground Wall	8ft (deep basement)	8ft R-10 interior, concrete	0.78	20.94	0.048	
Underground Floor	-	-	-	1000	0.001	Exposed parameter (Pexp) =0 ft

(Source: DOE-2 user news, Vol. 19, No. 1 by Fred Winkelmann)

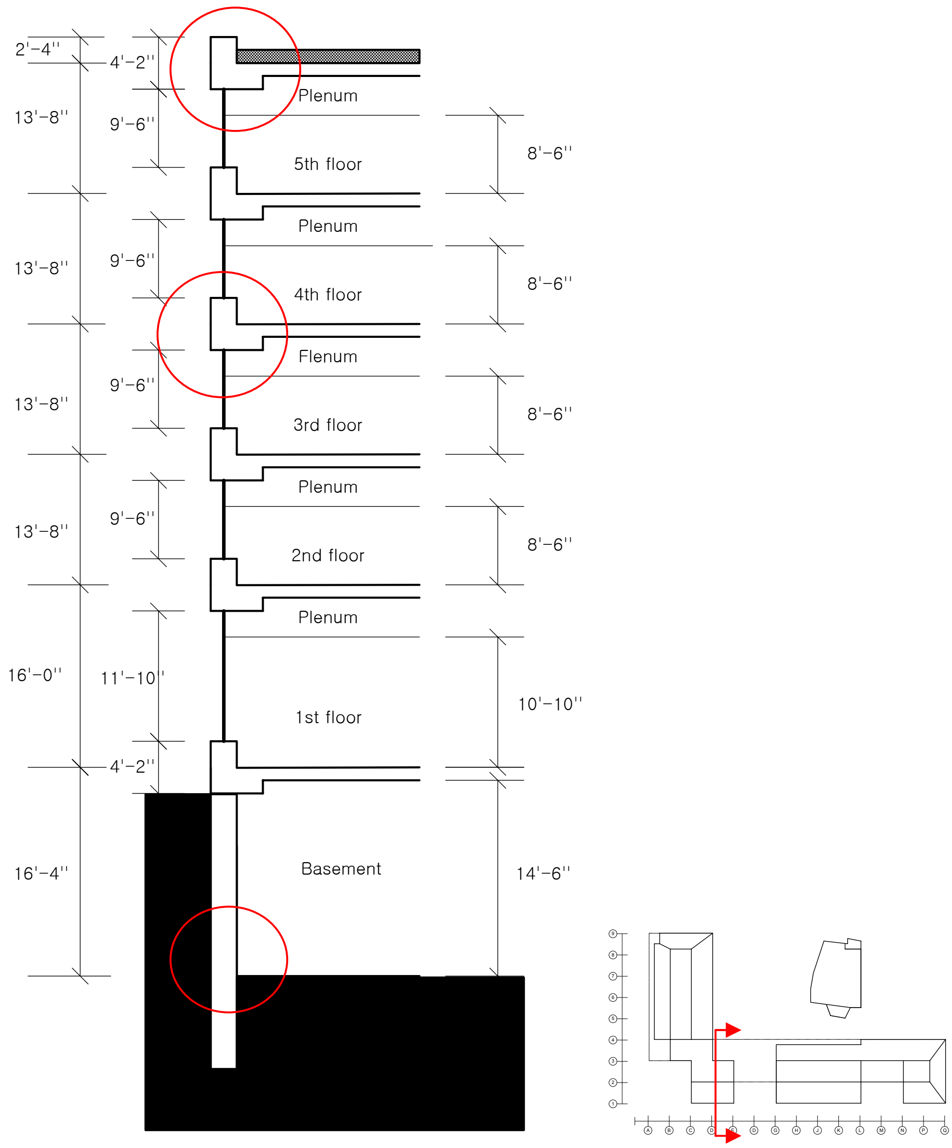
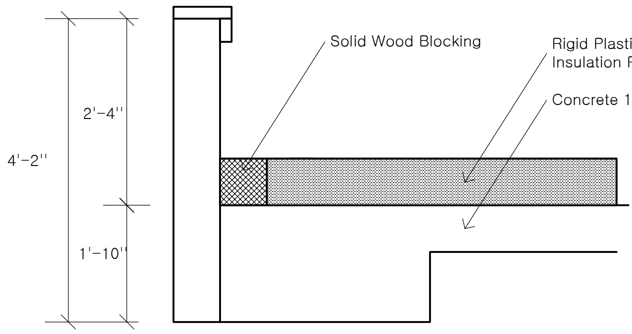
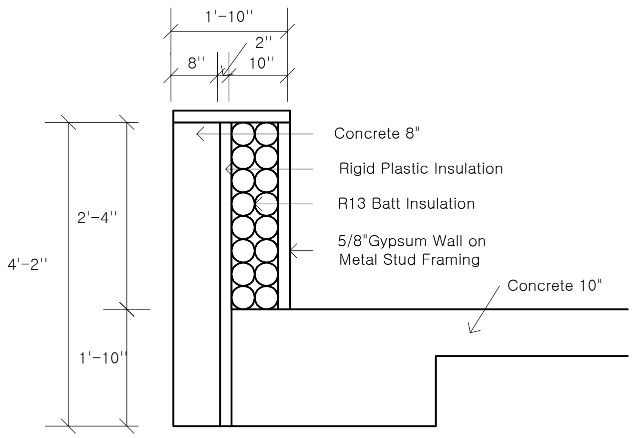


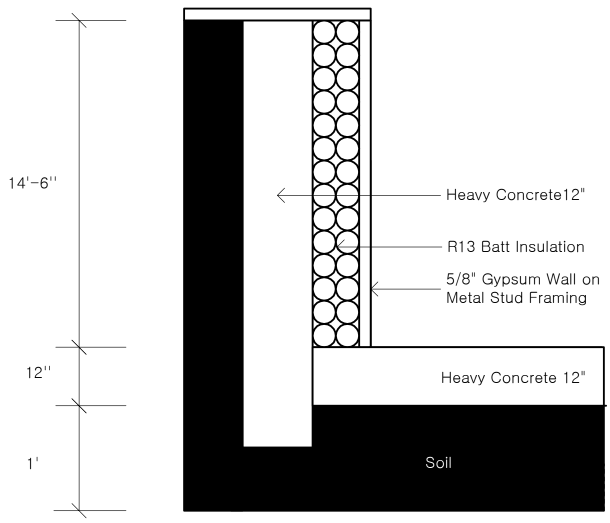
***Figure 6.5** A section of the REJ building.*



a) Roof



b) Typical floor



c) Underground wall and floor

Figure 6.6 *Section details of the REJ typical construction.*

6.1.1.3 Window Properties

Two types of low-e glazing were used in the case-study building, upper clearstory and the lower window area, as described in Chapter IV, Section 4.1. Window libraries for the two types of glazing were generated using the Window 5.2 program for the DOE-2 simulation of the case-study building. Table 6.6 shows that glazing properties generated using the Window 5.2 program have good agreement with data from the manufacturer, in terms of window layer, U-value, Solar Heat Gain Coefficient (SHGC), Shading Coefficient (SC), solar transmittance, and visible transmittance.

Table 6.6 Window Thermal Properties of the REJ Building

Properties		Window 5.2	Manufacturer	Description
Lower Part Window	Layer	VE140.VIR	VE 1-40	1/4" low-e Glazing
		Air	Air	1/2" Air space
		CLEAR_6.DAT	Clear	1/4" Clear Glazing
	U-Value	0.309	0.31	Winter Nighttime (Btu/hr-sqft-F)
	SHGC	0.277	0.28	Solar Heat Gain Coefficient
	SC	0.318	0.32	Shading Coefficient
	Tsol	0.207	0.21	Solar Transmittance
	Tvis	0.363	0.36	Visible Transmittance
Upper Part Window	Layer	VE12M.VIR	VE 1-2M	1/4" low-e Glazing
		Air	Air	1/2" Air space
		CLEAR_6.DAT	Clear	1/4" Clear Glazing
	U-Value	0.293	0.29	Winter Nighttime (Btu/hr-sqft-F)
	SHGC	0.378	0.38	Solar Heat Gain Coefficient
	SC	0.434	0.44	Shading Coefficient
	Tsol	0.325	0.33	Solar Transmittance
	Tvis	0.703	0.7	Visible Transmittance

(Note: All the thermal properties represent the values at normal incidence).

Furthermore, the solar transmittance from the Window 5.2 program was verified in this study with the transmittance coefficient from the DOE-2 hourly report (Variable #2), which is based on direct solar radiation transmitted through horizontal test glazing. Figure 6.7 shows the three test glazing on the top of the DOE-2 simulation model of the case-study building, including two types of the low-e (upper and lower part) glazing and a single clear glazing. As shown in Figure 6.8, DOE-2 solar transmittance shows a good fit below 50 degrees, but shows a symmetrical error to the Window 5 curve above 50 degree. The reason for this is unknown.

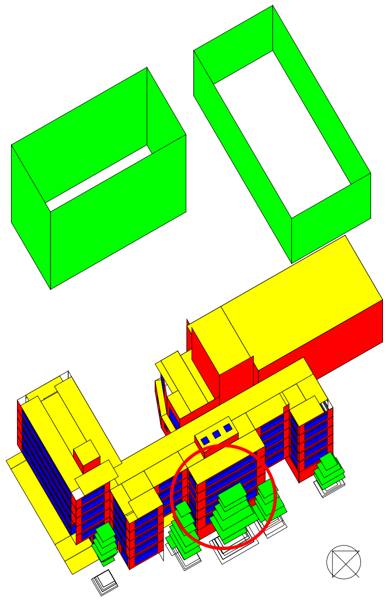


Figure 6.7 *Three test glazing on the top of the DOE-2 simulation model for the case-study building. (Note: using the DrawBDL program)*

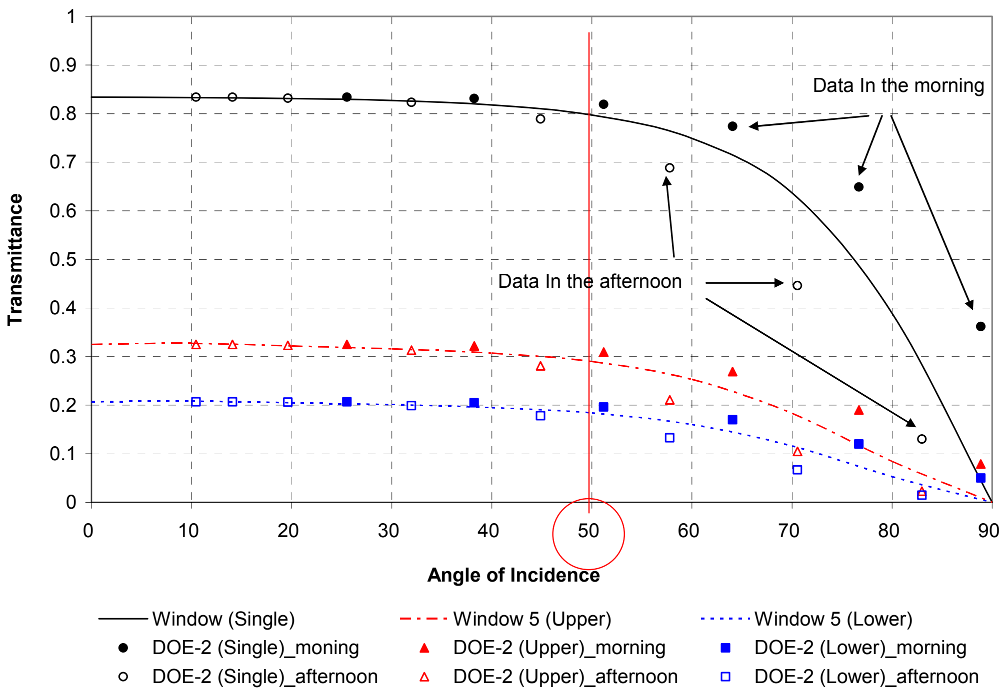


Figure 6.8 *Comparison of solar transmittance between Window 5.2 and DOE-2(Variable #2).*

6.1.1.4 Space Zoning and Conditions

Space zoning for the case-study building was established using interior and perimeter zones based on the as-built drawings. Figure 6.9 through Figure 6.12 show a plan view and space zoning used for the simulation of the basement, 1st floor, typical (2nd through 5th) floor, and 6th floor, respectively. Table 6.7 specifies the REJ office conditions, in terms of people, lighting, equipment, infiltration, and floor weight. Lighting and equipment load densities and schedules were determined based on the measured data using the ASHRAE RP-1093 toolkit (Abushakra et al., 2001) described in Chapter IV, Section 4.5.3. Figure 6.13 through Figure 6.16 represent the typical load day-types for weekday and weekend schedules in terms of whole-building lighting and receptacle loads. People schedules for the entire building were assumed from the 4th floor typical lighting schedules. The hourly values of the 50th percentile in the day-type plots were used in the DOE-2 schedules in the REJ as-built simulation. No infiltration was assumed in the DOE-2 simulation because the HVAC is always on and the building is assumed to be pressurized. The floor weight was initially assumed to be 70 lb/sqft, which is the DOE-2 default value for a medium construction. This pre-calculated weighting factor was later changed to a custom-weighting factor for the 2001 as-built model calibration, which is described in Chapter VI, Section 6.2.

Table 6.7 Space Conditions of the REJ Building

DOE-2 Keywords	2001 As-built Model (Office)	Description
TEMP	71	Midpoint of heating and cooling setpoint
ARES/PERSON	275	Number of People (Around 1100)
PEOPLE-HG-SENS	230	
PEOPLE-HG-LAT	190	
PEOPLE-SCHEDULE	OCCUP-1	Based on 4th Floor Lighting Schedule (RP-1093)
LIGHTING-TYPE	SUS-FLOOR	
LIGHTING-W/SQFT	1.27	Measured
LIGHTING-SCHUDULE	LIGHT-1	Measured (RP-1093)
LIGHT-TO-SPACE	0.9	DOE-2 Default
EQUIPMENT-W/SQFT	0.74	Measured
EQUIP-SCHEDULE	EQUIP-1	Measured (RP-1093)
INF-METHOD	Air-change	
AIR-CHANGE/HR	0	HVAC is always on
INF-SCHEDULE	INFIL-SCH	
FLOOR-WEIGHT	70 lb/sqft	DOE-2 default for a medium construction

The space zoning in the basement was identical to the HVAC zoning described in Section 6.2.2. Figure 6.9 shows the basement floor plan and space zoning. Internal loads in the basement were grouped into four groups as shown in Table 6.8. The electricity for the computer room was fed from the building's emergency electrical panels. On-site measurements were used to measure the electricity use from the computer room. These measurements show the average electricity use was 84 kWh/h, including: computer, lighting, and Computer Room Unit (CRU) electricity use. The electricity use for the CRU was assumed to be 32 kW, which represents 50% of the total design fan electricity use (64 kW) horse power (HP) specified in the as-built drawing. Electricity use for the print shops and conference room was also measured separately from each breaker that supplied the print shops and conference center. Figure 6.17 through Figure *6.22* represent the typical weekday and weekend load day-types of the lighting and receptacle loads for the print shop and conference center.

Table 6.8 Measured Data for End-use Electricity Use

Items	DOE-2 Input Values	Schedule	Description
Computer Room	52 (kW)	LIGHT-2	On-site Measurement (84 kWh/h) Include equipment and CRU (32 kWh/h)
Senate Print Shop	3.86 (W/SQFT)	EQUIP-S	Measured (RP-1093)
DP(TLC) Print Shop	4.65 (W/SQFT)	EQUIP-T	Measured (RP-1093)
Conference Room	2.04 (W/SQFT)	EQUIP-C	Measured (RP-1093)
Parking Lots	64.818 (KW)	LIGHT-2	On-site Measurement
Ground Lighting	8 (KW)	ELIGHT	Sunrise and Sunset (12kw), Constant (2kw)

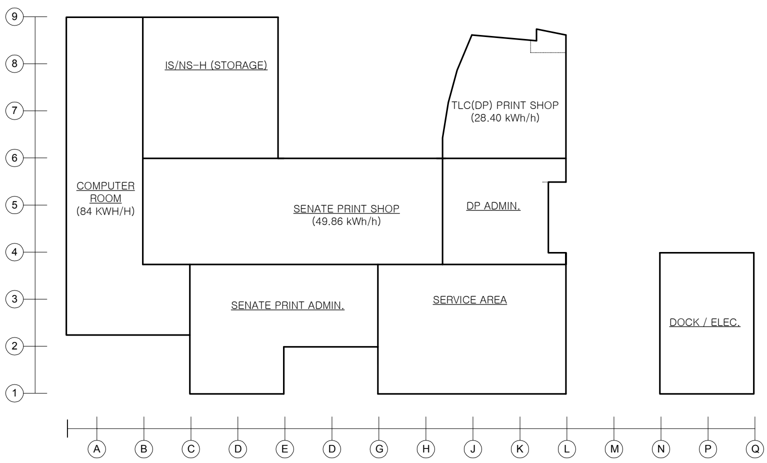


Figure 6.9 *Basement plan with space zoning.*

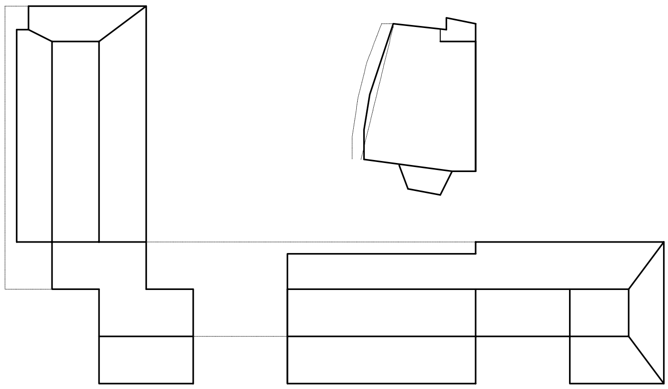


Figure 6.10 *The 1st floor plan with space zoning.*

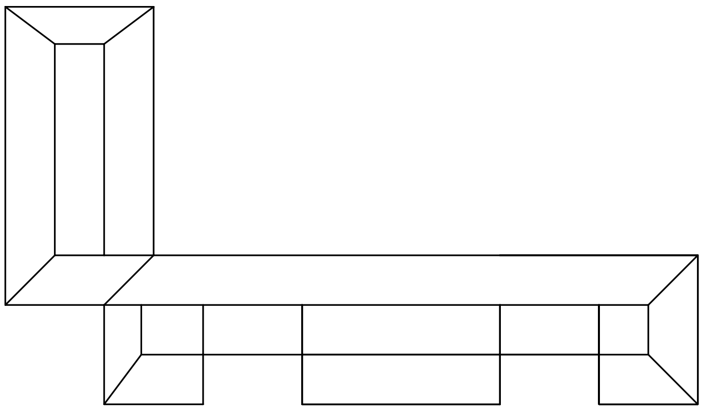


Figure 6.11 *Typical floor plan with space zoning (2nd – 5th).*

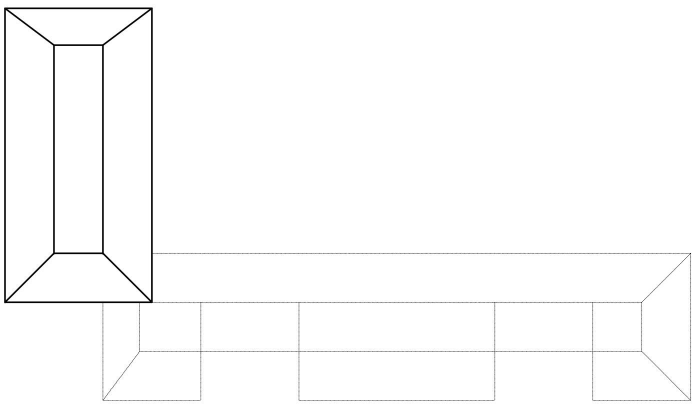


Figure 6.12 *The 6th floor plan with space zoning.*

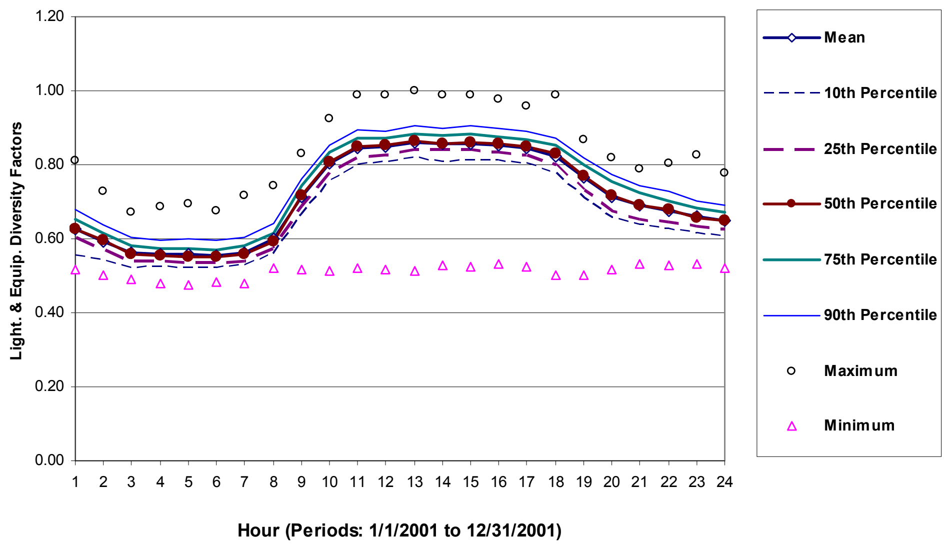


Figure 6.13 *Weekday lighting and equipment schedule (WBE-MCC) of the REJ building. (Note: The dates that are excluded from the weekday profile are as follows: 1/1/01, 1/5/01, 1/8/01, 7/4/01, 11/15/01, 11/22/01, 11/23/01, 12/24/01, 12/25/01, and 12/26/01)*

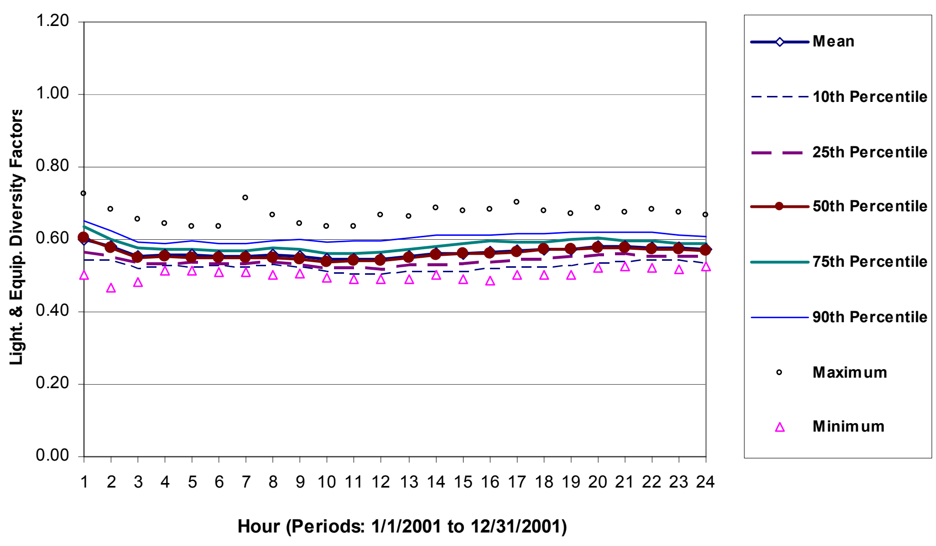


Figure 6.14 *Weekend lighting and equipment schedule of the REJ building. (Note: The dates that are excluded from the weekday profile are as follows: 1/6/01, 1/7/01, 4/1/01 and 9/29/01)*

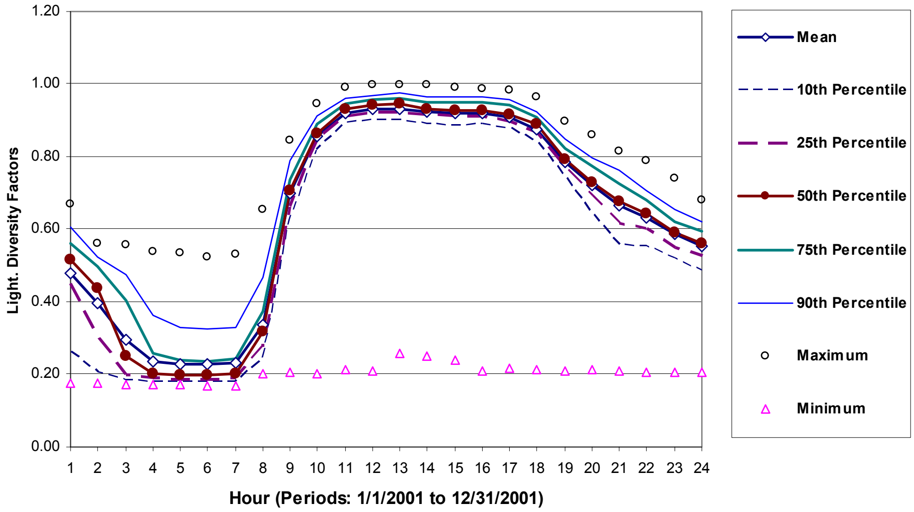


Figure 6.15 *Typical weekday occupancy schedule of the REJ building.*
(Note: The dates that are excluded from the weekday profile are as follows: 1/1/01, 7/4/01, 11/22/01, 11/23/01, 12/24/01, 12/25/01, and 12/26/01).

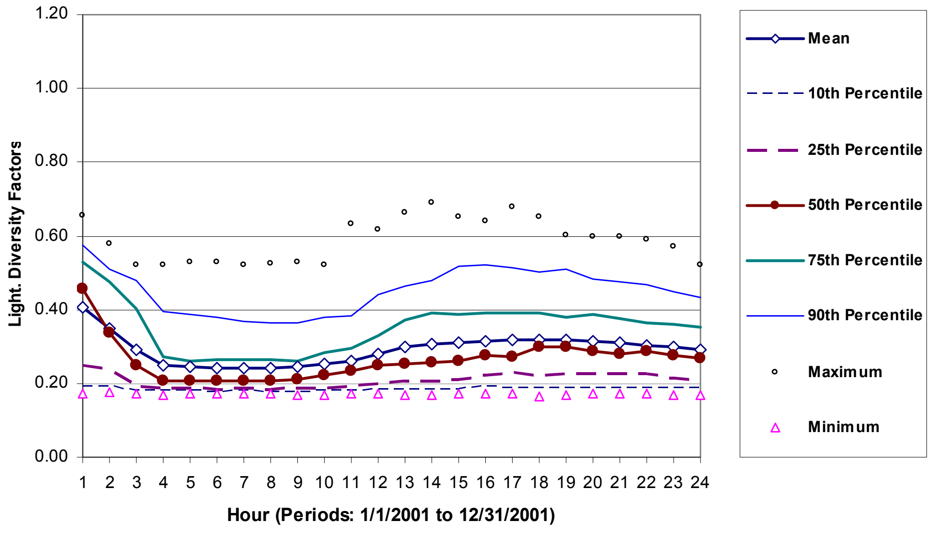


Figure 6.16 *Typical weekend occupancy schedule of the REJ building.*
(Note: The dates that are excluded from the weekday profile are as follows: 4/1/01 and 9/29/01).

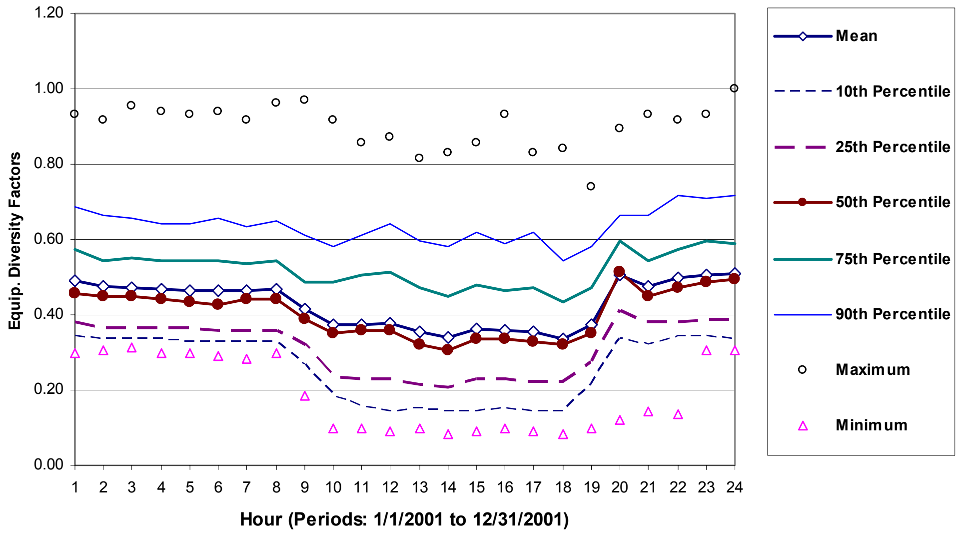


Figure 6.17 *DOE-2 equipment weekday schedule of the conference center in the REJ building. (Note: The dates that are excluded from the weekday profile are as follows: 1/1/01, 7/4/01, 11/22/01, 11/23/01, 12/24/01, 12/25/01, and 12/26/01).*

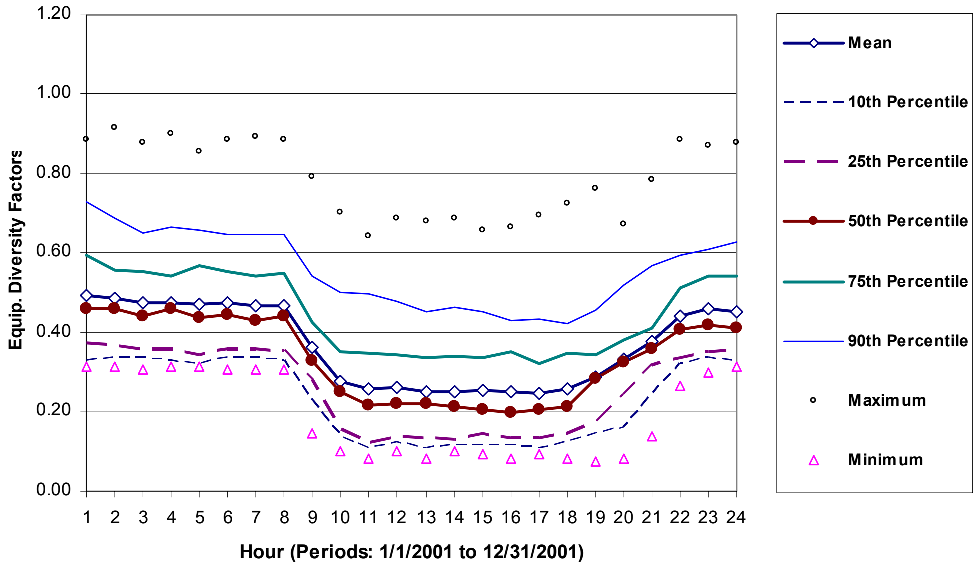


Figure 6.18 *DOE-2 equipment weekend schedule of the conference center in the REJ building. (Note: The dates that are excluded from the weekday profile are as follows: 4/1/01 and 9/29/01).*

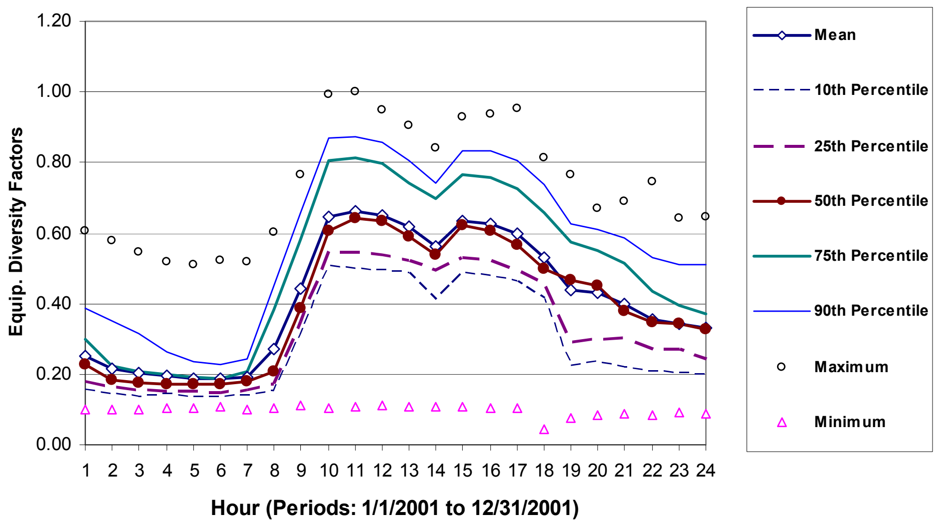


Figure 6.19 *Equipment weekday schedule of the senate print shop in the REJ building. (Note: The dates that are excluded from the weekday profile are as follows: 1/1/01, 7/4/01, 11/22/01, 11/23/01, 12/24/01, 12/25/01, and 12/26/01).*

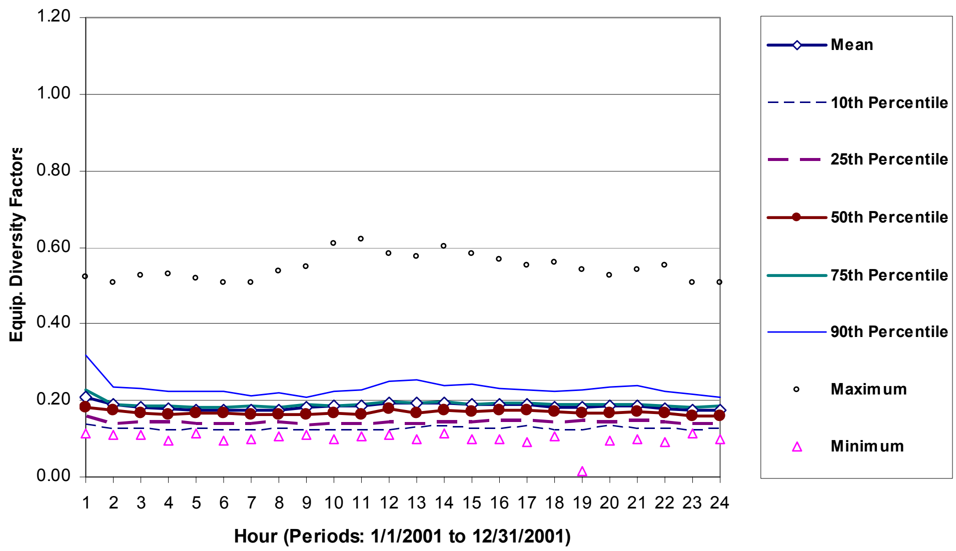


Figure 6.20 *Equipment weekend schedule of the senate print shop in the REJ building. (Note: The dates that are excluded from the weekend profile are as follows:4/1/01 and 9/29/01).*

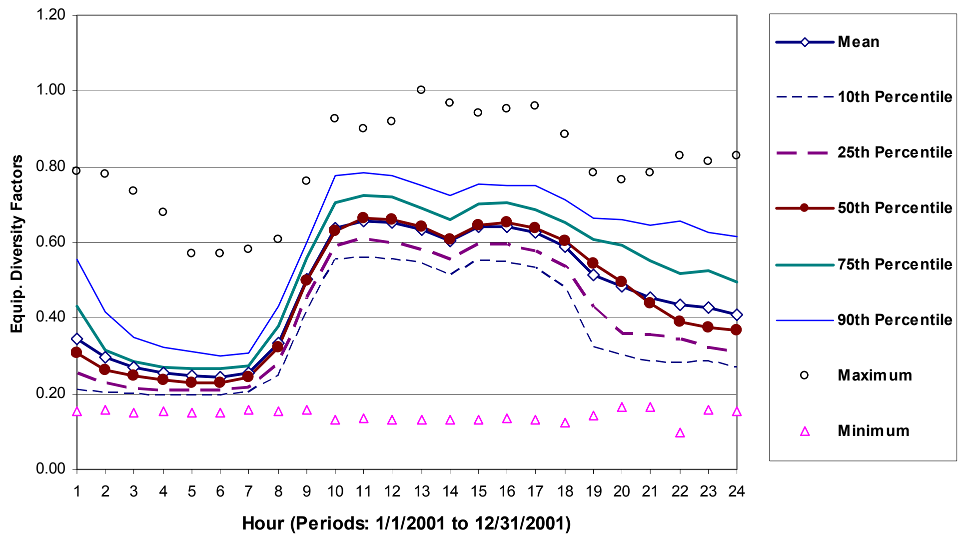


Figure 6.21 *Equipment weekday schedule of the TLC print shop in the REJ building. (Note: The dates that are excluded from the weekday profile are as follows: 1/1/01, 7/4/01, 11/22/01, 11/23/01, 12/24/01, 12/25/01, and 12/26/01).*

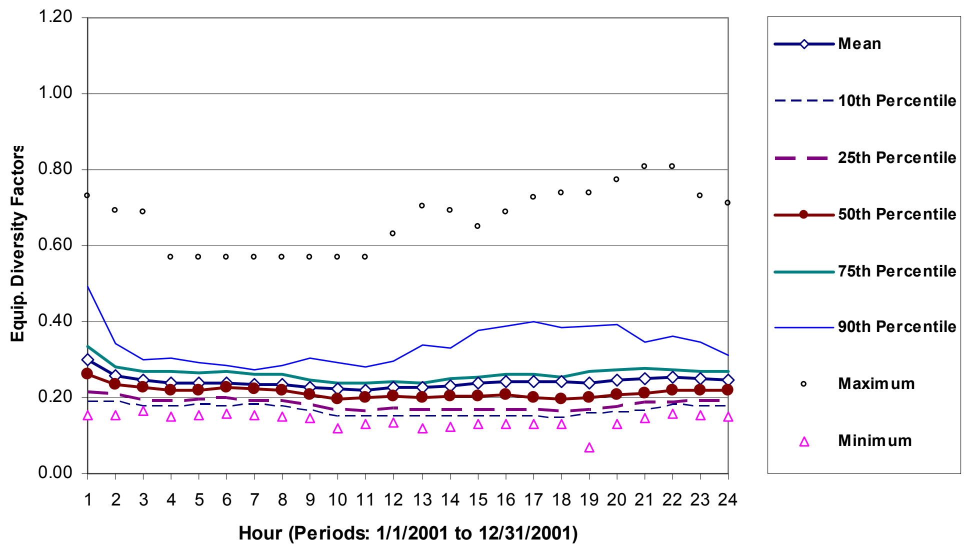


Figure 6.22 *Equipment weekend schedule of the TLC print shop in the REJ building. (Note: The dates that are excluded from the weekend profile are as follows: 4/1/01 and 9/29/01).*

6.1.2 SYSTEMS

As described in Chapter IV, Section 4.1, the majority of the conditioned area in the REJ building is served by a Dual-duct, Variable Air Volume (DDVAV) system. The dual-duct system has mixing boxes capable of reducing flow in response to a decrease in cooling demand for each control zone. In DOE-2, a number of optional components in dashed boxes are shown in Figure 6.23.

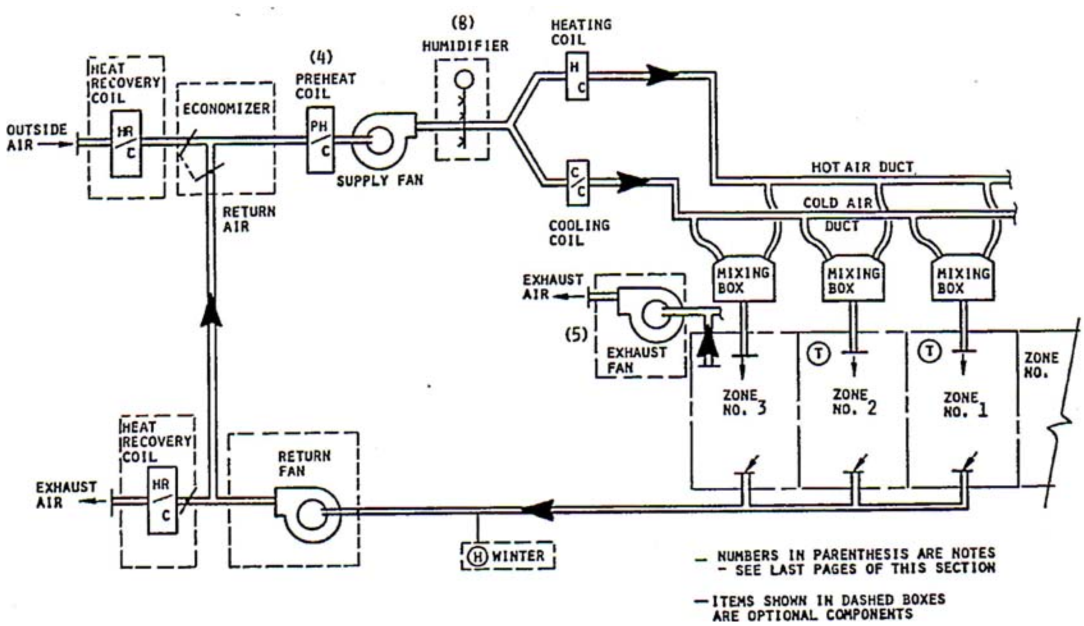


Figure 6.23 *DOE-2 Dual-duct Variable Air Volume (DDVAV) system (LBL, 1982).*

Table 6.9 shows the DOE-2 keywords and values used for the DDVAV system in the case-study building. The cooling and heating set-point was 71 ^{o}F based on measured return air temperature as described in Chapter V, Section 5.4. Reverse-action type thermostats were used for modeling the variable-air volume system. The thermostat allows the supply air flow rate to increase above minimum flow rate as defined in MIN-CFM-RATIO, which was set to 0.6 for the case-study building. Supply air temperatures leaving each heating and cooling coil were set 105 ^{o}F and 55 ^{o}F, respectively. The heating coil air temperature was then calibrated to the as-built model with measured data, which is described in Chapter

IV, Section 6.2.4. Minimum outside air flow was first assigned to each zone, but later was changed to 10% of the total supply air flow in the process of model calibration as described in Chapter, Section 6.2.1.

Table 6.9 DOE-2 SYSTEM Model for the Typical AHU (DDVAV) of the REJ Building

Items	DOE-2 Keywords	DOE-2 Model	Description
ZONE	-	Office	
ZONE - CONTROL	HEAT-TEMP-SCHEDULE	SCH207	71 °F
	COOL-TEMP-SCHEDULE	SCH208	71 °F
	THERMOSTAT-TYPE	Reverse-Action	VAV system
SYSTEM	SYSTEM TYPE	DDVAV	
	RETURN-AIR-PATH	PLENUM	From as-built drawing
SYSTEM – CONTROL	MIN-SUPPLY-TEMP	55	DOE-2 Default
	COOL-SET-TEMP	55	DOE-2 Default
	COOL-CONTROL	CONSTANT	
	MAX-SUPPLY-TEMP	105	DOE-2 Default
	HEAT-SET-TEMP	105	DOE-2 Default
	HEAT-CONTROL	CONSTANT	
	PREHEAT-TEMP	50	
SYSTEM - AIR	MIN-OUTSIDE-AIR	Assigned to each zone	From as-built drawing
	OA-CONTROL	Assigned to each zone	From as-built drawing
SYSTEM – FAN	FAN-SCHEDULE	SCH202	
	SUPPLY-STATIC	4	
	SUPPLY-EFF	0.51	From as-built drawing
	MOTOR-PLACEMENT	IN-AIRFLOW	
	FAN-CONTROL	SPEED	
	SUPPLY-MECH-EFF	0.51	
SYSTEM - TERMINAL	MIN-CFM-RATIO	0.6	
	REHEAT-DELTA-T	-	

For the basement HVAC system, four types of systems were used according to each space need, including: a bypass multi-zone system, a single-duct variable air volume system (VAV) without heating coil, a single-duct constant air volume (CAV) system with a humidifier, a heat wheel heat-recovery unit (not simulated), and Computer Room Units (CRUs). Figure 6.24 shows the basement zoning for the DOE-2 simulation used in this study. Table 6.10 shows the DOE-2 system model for each AHU in the REJ building. Selected control values are also shown based on the EMCS data as shown in Figure 6.25 through Figure 6.28. Figure 6.25 shows the by-pass multi-zone constant air volume system (CAV). Figure 6.26

shows the single-duct constant air volume system (CAV) with electric steam humidifier. Figure 6.27 shows the single-duct constant air volume system (CAV) with heat recovery system (Heat wheel type), which was not simulated. Figure 6.28 shows the single-duct variable air volume (VAV) units without heating coils.

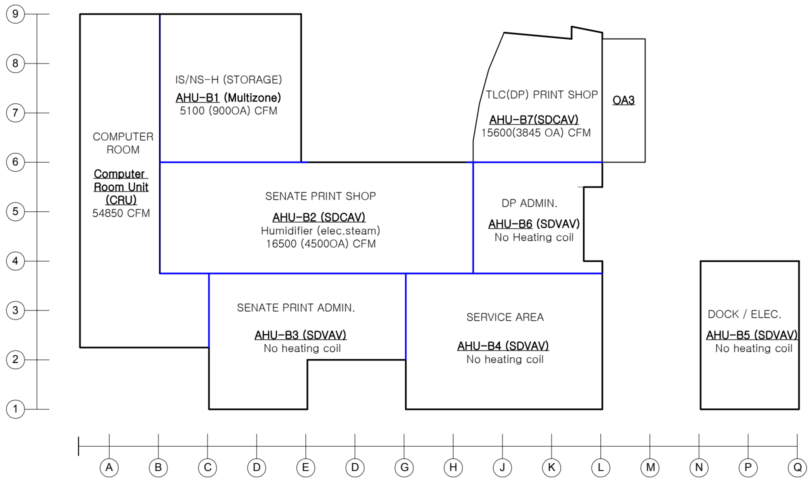


Figure 6.24 *DOE-2 basement system zoning of the REJ building.*

Table 6.10 DOE-2 AHUs System Model of the Case-study Building

DOE-2 Keywords	2001 As-built Model						Remarks
ZONE	Office	Conference (Storage)		Print shop		Computer Room	
		Conf.	Storage	Senate	DP(TLC)		
COOL-TEMP-SCH	71	71	72	70	72	71	71
HEAT-TEMP-SCH	No heat (32)	71	-	66	68	-	71
SYSTEM-TYPE	SZRH (VAV)	Multizone (CAV)		SZRH (CAV)		PSZ (CAV)	
AHU NAME	AHU-B3,B4,B5	AHU-C1	AHU-B1	AHU-B2	AHU-B7	CRU	
THERMOSTAT-TYPE	Reverse-Action	Proportional					
MIN-CFM-RATIO	0.6	1					
OA-CONTROL	Fixed	Fixed		Fixed		Fixed	
FAN-CONTROL	Speed	Constant		Constant		Constant	
SUPPLY-KW	0.00105	0.00122	0.00159	0.00159	0.00125	0.00087	kW/CFM
SUPPLY-MECH-EFF	0.51	0.45	0.3	0.35	0.4	0.4	CFM*In.wg / HP* 6356
REHEAT-DELTA-T	-	50		50		-	
HUMIDIFIER-TYPE	-	-		ELECTRIC		-	
MAX-HUMIDITY	-	-		0.6	0.6 (0.55)	-	
MIN-HUMIDITY	-	-		0.4 (0.5)	0.4	-	

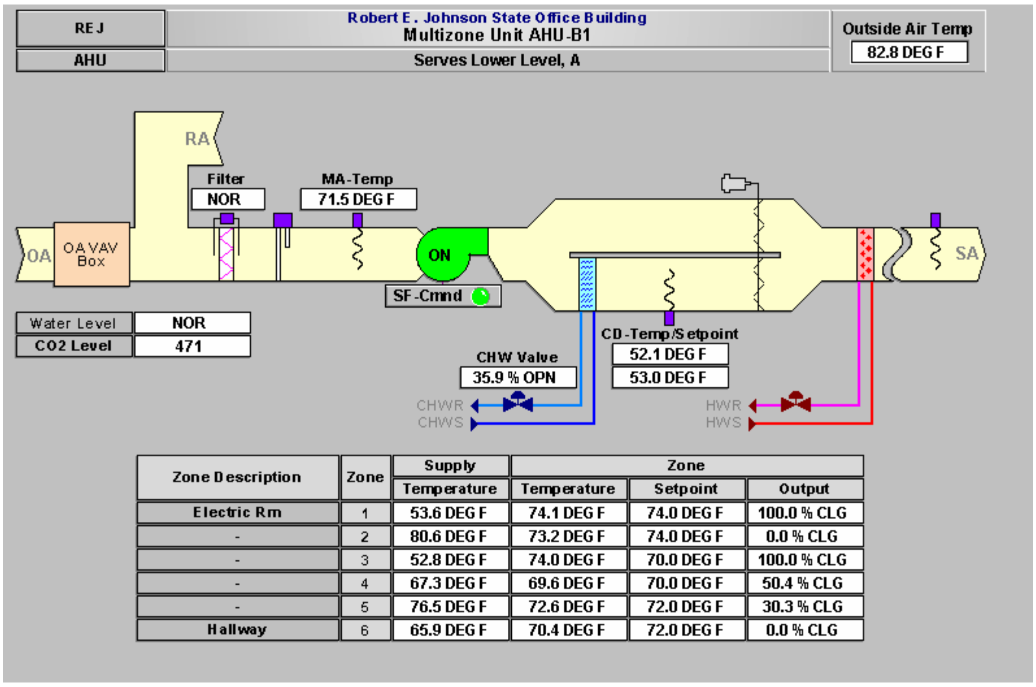


Figure 6.25 *By-pass multi-zone Constant Air Volume System (CAV). (Source: Picture taken from the EMCS Monitor).*

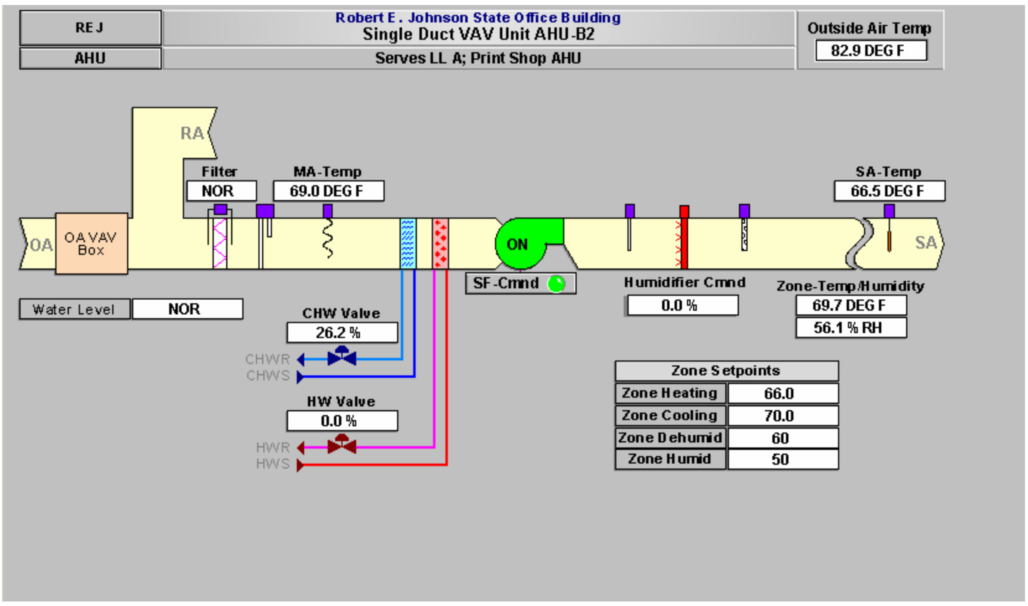


Figure 6.26 *Single-duct Constant Air Volume System (SDCAV) with electric steam humidifier. (Source: Picture taken from the EMCS Monitor).*

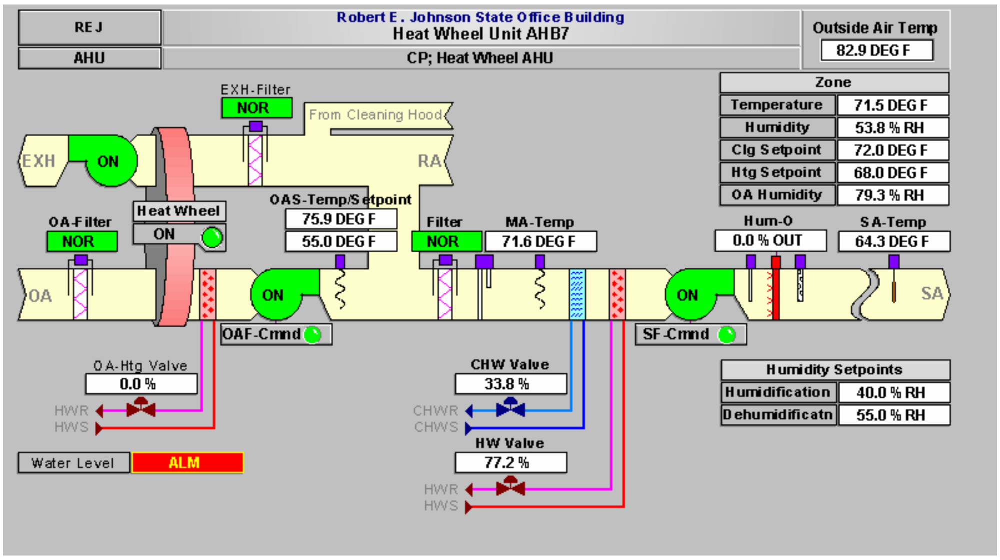


Figure 6.27 *Single-duct Constant Air Volume System (SDCAV) with Heat Recovery (Heat Wheel). (Source: Picture taken from the EMCS Monitor).*

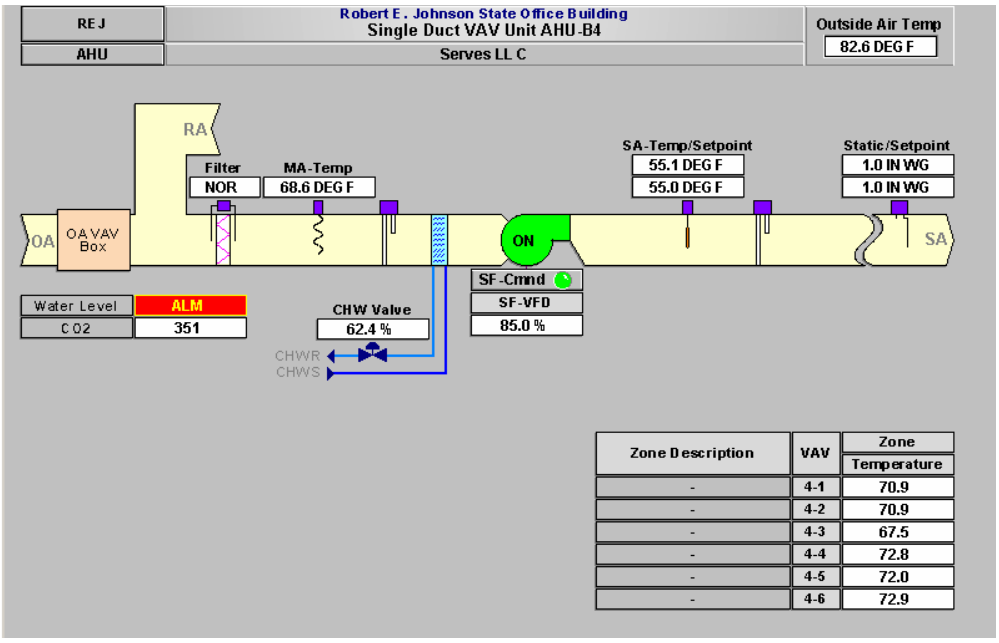


Figure 6.28 *Single-duct Variable Air Volume (SDVAV) unit monitoring diagram (AHU-B4). (Source: Picture taken from the EMCS Monitor).*

6.1.3 PLANT

As described in Chapter IV, Section 4.1, the REJ building contains high efficiency mechanical equipment, including: two low-NOx boilers, three high efficiency centrifugal chillers, two over-sized cooling towers, and other miscellaneous pumps. Table 6.11 summarizes the DOE-2 PLANT model for the as-built simulation of the case-study building. According to the manufacturer's specification, the two low-NOx boilers have a normal rated output capacity of 4.2 MMBtu with a Heat-Input-Ratio (HIR) of 1.19. The two centrifugal chillers have a normal cooling capacity of 5.58 MMBtu (465 ton) with an Electric-Input-Ratio (EIR) of 0.1547 (6.59 COP). The two cooling towers have an over-sized output capacity of 12 MMBtu (1,000 ton) with an Electric-Input-Ratio (EIR) of 0.0045, which is determined by the fan power consumption of an open tower to 0.0154 hp/gpm (0.0105 Btu/Btu) at the CTI rating conditions in DOE-2 (LBNL, 1993). Hot water and cold water are circulated with variable speed pumps with 35 ft and 50 ft of head, respectively.

Table 6.11 DOE-2 Plant Model of the REJ Building

Items	DOE-2 Model	Description
BOILER	HW Boiler	PVI Industries (125 WBE 250A-TP)
SIZE	4.2	MMBtu
INSTALL NUMBER	2	
ELEC-INPUT-RATIO	0.022	
HW-BOILER-HIR	1.19	Input (4.98)/ Output(4.185)
CHILLER	HERM-CENT-CHLR	TRANE (CVHF-555)
SIZE	5.58 (465 TON)	MMBtu
INSTALL NUMBER	2	
ELEC-INPUT-RATIO	0.1547	0.544 (kW/ton) ; 6.59 COP
TOWER	OPEN-TWR	
SIZE	12	MMBtu
INSTALL NUMBER	2	
ELEC-INPUT-RATIO	0.00455	(20 hp/3000gpm)*0.6818
TWR-CAP-CTRL	VARIABLE- SPEED-FAN	
TWR-PUMP-HEAD	18	Feet
PUMP		
CCIRC-PUMP-TYPE	VARIABLE- SPEED	
CCIRC-HEAD	50	Feet
HCIRC-PUMP-TYPE	VARIABLE- SPEED	
HCIRC-HEAD	35	Feet

6.2 2001 As-built Model Calibration

This Section describes the calibration methods and results for each run. The 2001 as-built simulation model described in Chapter IV, Section 6.1 was used as the base model to further calibrate the simulation until it reached an acceptable goodness-of-fit. As described in Chapter IV, Section 4.5.7, calibration signatures for heating, cooling, and electricity were developed from each run, which were then used to evaluate the effectiveness of the measure being evaluated. Table 6.12 shows the calibration factors used for each run, including: (1) Supply air and outside air (OA) flow rate (2) Building thermal mass, (3) Duct air loss, (4) Max. supply air temperature, and (5) Measured weather file with calculated direct normal solar radiation. In the following Section, calibration factors are described with the calibration results for each calibration step.

Table 6.12 DOE-2 Calibration Factors in Each Run

Calibration Factors		Base Model	Run1	Run2	Run3	Run4	Run5
1	Supply Air Flow	Assigned CFM	Auto calculated	Auto calculated	Auto calculated	Auto calculated	Auto calculated
	Outside Air Flow	Assigned CFM	0.1	0.1	0.1	0.1	0.1
2	Weighting Factor	Pre-calculated	Pre-calculated	Custom	Custom	Custom	Custom
3	Duct Air Loss	0	0	0	0.3	0.3	0.3
4	Max Supply Temp.	105	105	105	105	95/75	95/75
5	Direct Normal Solar Radiation	Measured	Measured	Measured	Measured	Measured	Calculated

Figure 6.29 shows the calibration signatures developed from the as-built base model. The calibration signatures include the 25th, 50th, and 75th percentiles to help identify the deviation between measured and simulated results according to dry-bulb temperature. The calibration signatures in Figure 6.30 indicated that simulated cooling energy should be increased up to 25% according to dry-bulb temperature and the simulated heating energy should be decreased up to 20%. The simulated electricity use should also be reduced in the overall temperature range. As shown in Figure 6.30, characteristic signatures were developed in this study as a graphical index to determine which simulation parameters and how much parameter values should be changed to improve the simulation results, when compared with the calibration signature developed from each run.

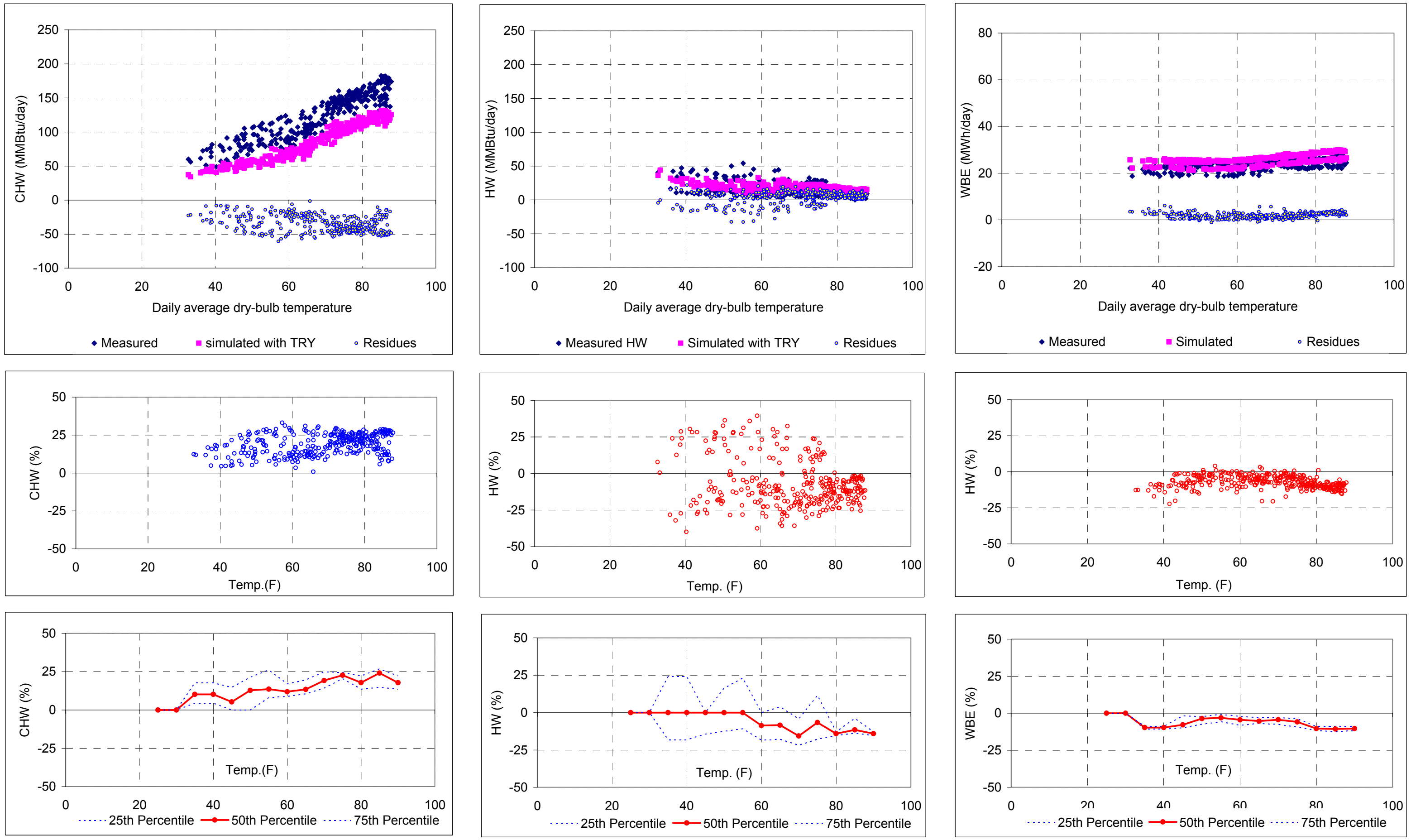
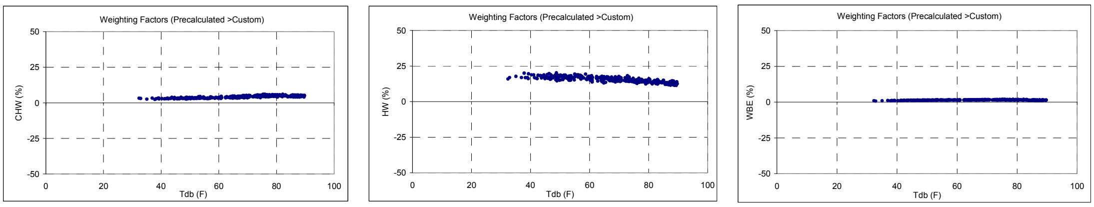
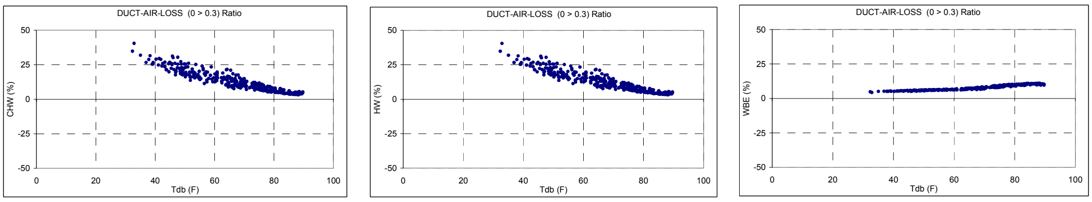


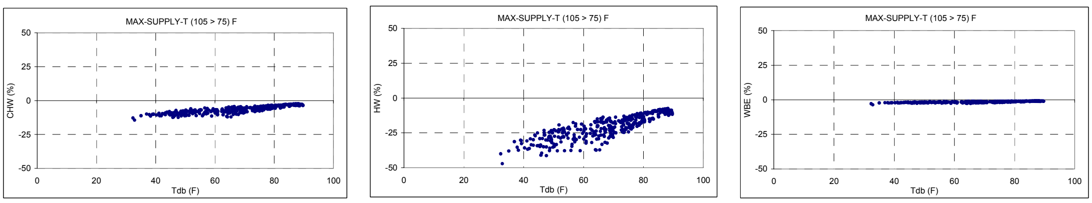
Figure 6.29 *Calibration signatures of the as-built base model simulation.*



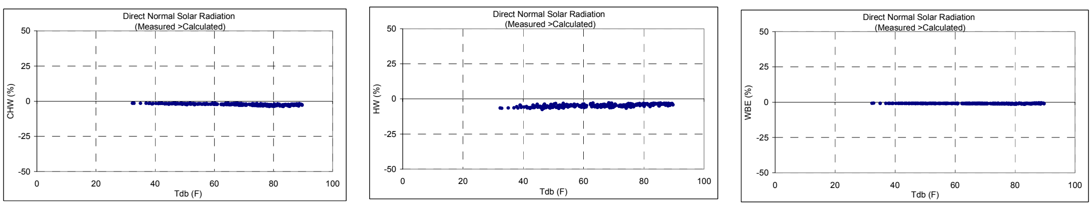
a) Characteristic signature for No. 2 custom weighting factor (Pre-calculated to custom)



b) Characteristic signature for No. 3 duct-air-loss (0 to 0.3)



c) Characteristic signature for No. 4 max. supply temperature (105 ^oF to 75 ^oF)



d) Characteristic signature for No. 5 direct normal solar radiation (Measured to calculated)

Figure 6.30 *Characteristic signatures for each calibration factor.*

6.2.1 The 1st Run: Supply Air and Outside Air Flow Rate

The as-built base simulation was modeled with assigned CFMs for the supply and outside air flow rate based on the design information from the as-built drawing as described in Chapter IV, Section 4.2.1. As a result, the simulated system electricity use was much higher than the measured data (WBE-Chiller) as shown in Figure 6.31. In this calibration step, instead of an assigned CFM, the minimum supply air flow rate was set to 0.6 for the VAV systems, and the outside air flow rate was a 10 % in proportion to the total supply air flow for all the AHU systems. Figure 6.32 shows the system electricity use after this calibration with the adjusted supply and outside air flow rate, respectively. Figure 6.33 shows that the whole-building electricity (WBE) use improved with the measured data after the first run.

6.2.2 The 2nd Run: Building Thermal Mass Effect

Custom Weighting Factors (CWFs) were used to consider the building thermal mass effect in DOE-2. From the characteristic signatures in Figure 6.30, the heating and cooling energy was expected to increase. Figure 6.34 shows the results from the second run with the CWFs. In the second run, the heating and cooling energy increased as expected, but not enough to match with measured cooling energy use.

6.2.3 The 3rd Run: Undocumented Exhaust Air

Undocumented exhaust air out of the case-study building was considered using the DUCT-AIR-LOSS command in DOE-2, which significantly increased heating, cooling, and electricity energy use in the characteristic signatures as shown in Figure 6.30. In Figure 6.35, the base model had a much lower cooling load than the measured data. From the cooling load comparison between simulated and measured data, a 30% duct-air-loss was defined for the DOE-2 calibration, which includes about 10% exhaust air from the exhaust fans installed on the roof of the case-study building. The rest of 20% exhaust air was assumed to be unknown from the basement print shop. As a result, Figure 6.36 shows improved agreement for the cooling loads. However, heating and electricity energy use needed further calibration. Figure 6.37 shows the cooling loads after the third run with a 30% of undocumented air loss.

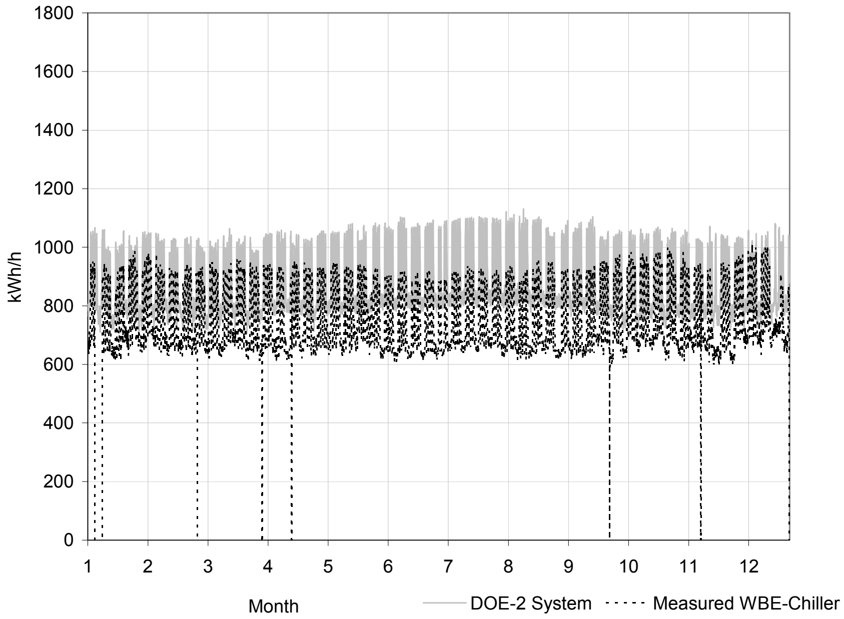


Figure 6.31 *Building system electricity use before the 1st run with assigned CFM for supply and outside air flow.*

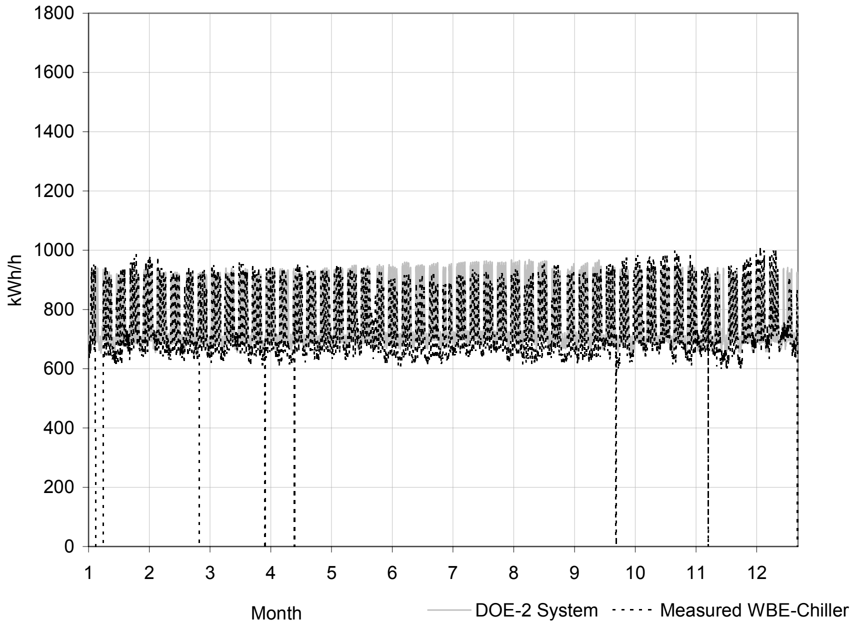


Figure 6.32 *Building system electricity use after the 1st run with adjusted supply and outside air flow rate.*

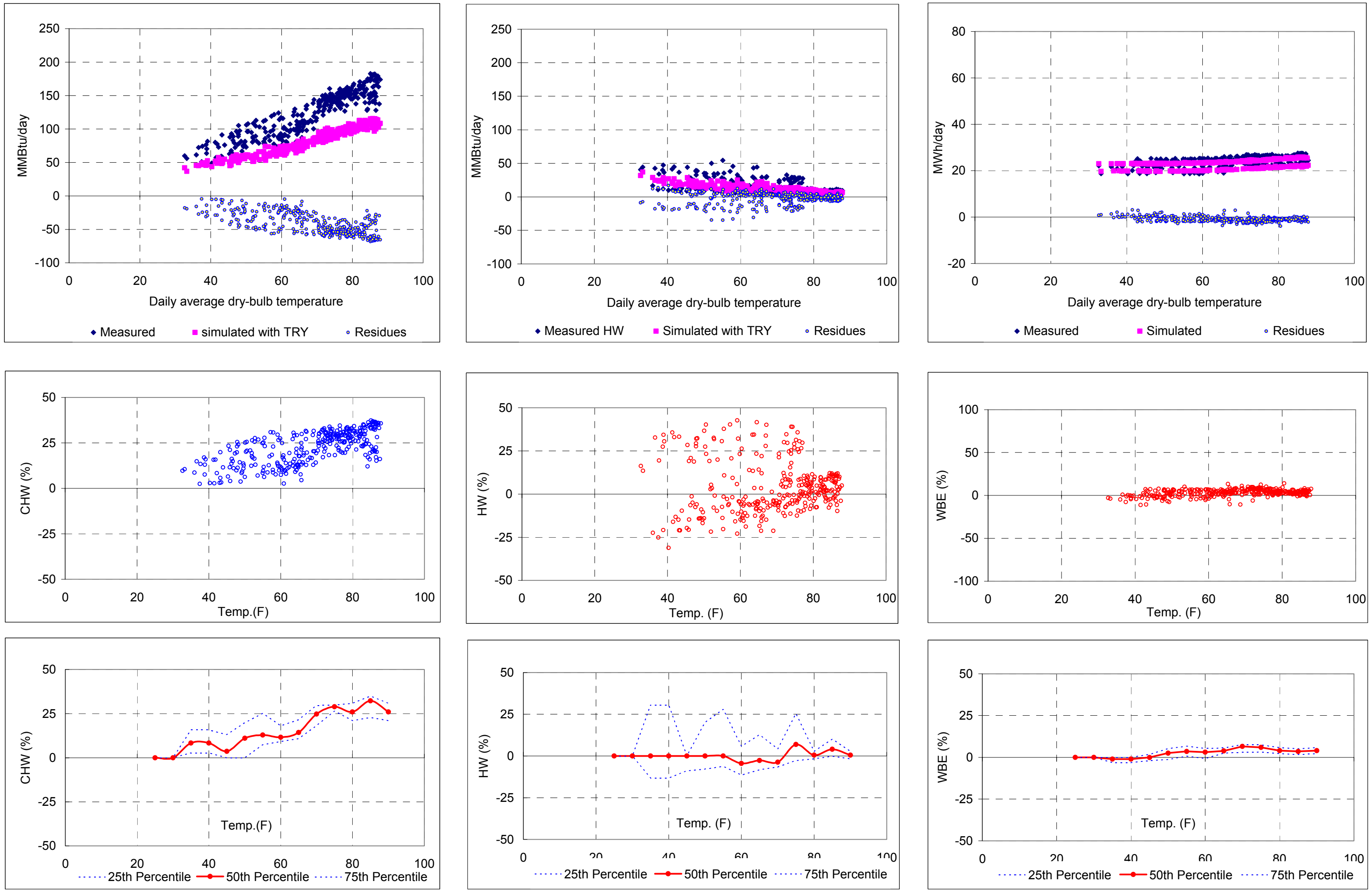


Figure 6.33 *Calibration signature after the 1*st *run with an adjusted supply and outside air flow rate.*

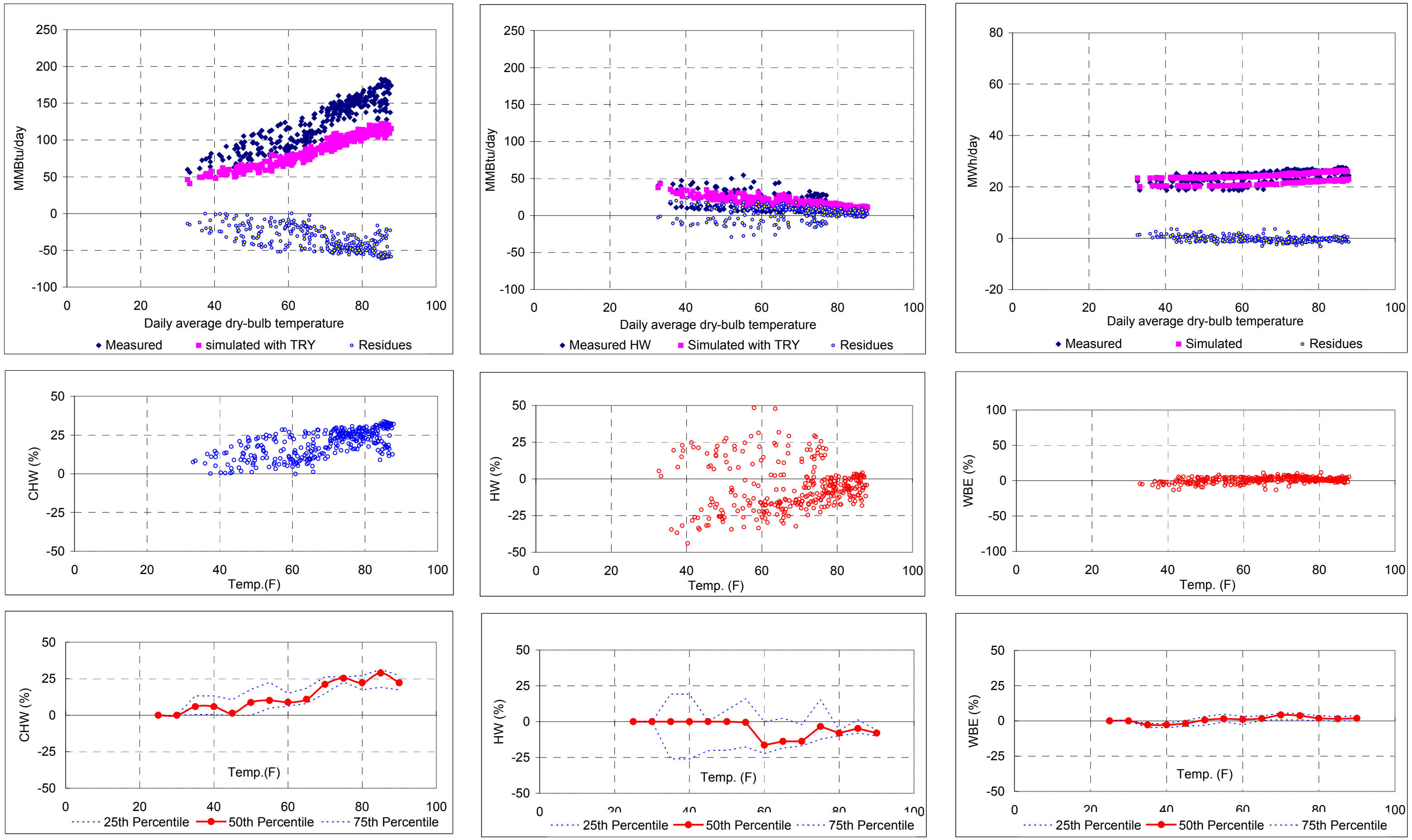


Figure 6.34 *Calibration signature after the 2nd run with Custom Weighting Factors.*

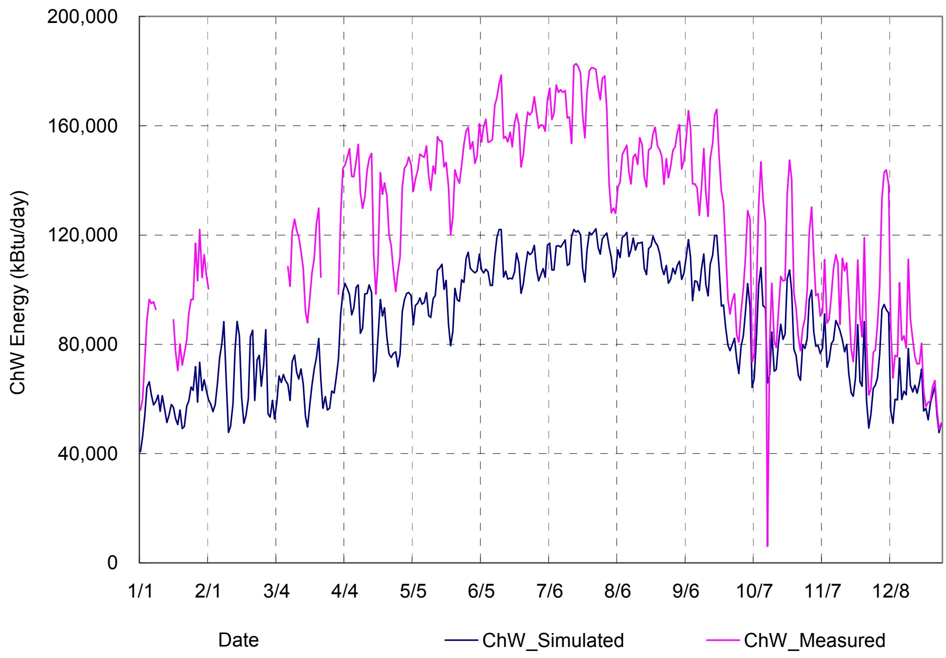


Figure 6.35 *Cooling energy use after the 2nd run without undocumented air loss.*

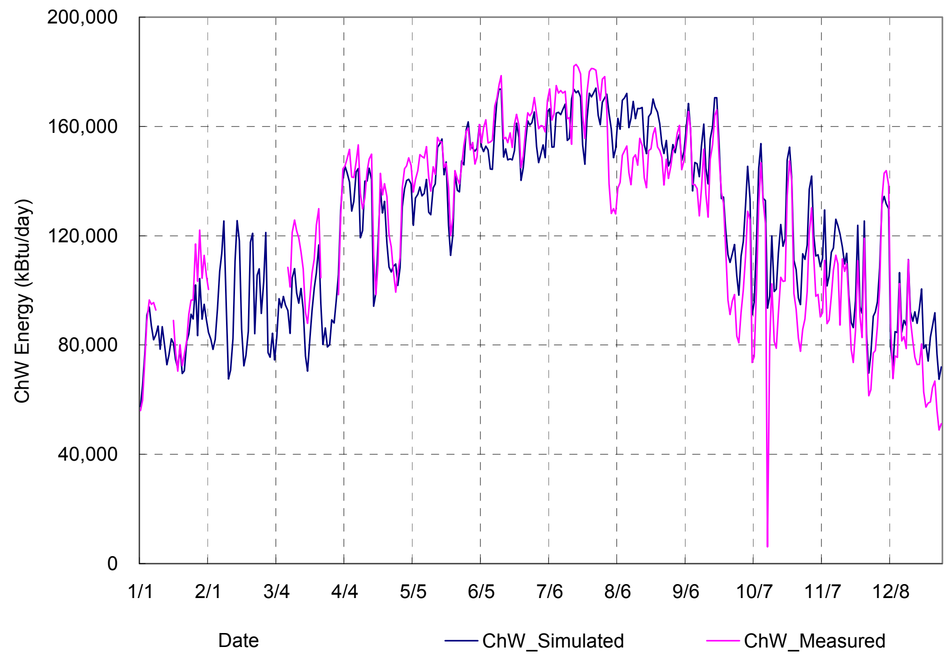


Figure 6.36 *Cooling energy use after the 3rd run with a 30% of undocumented air loss.*

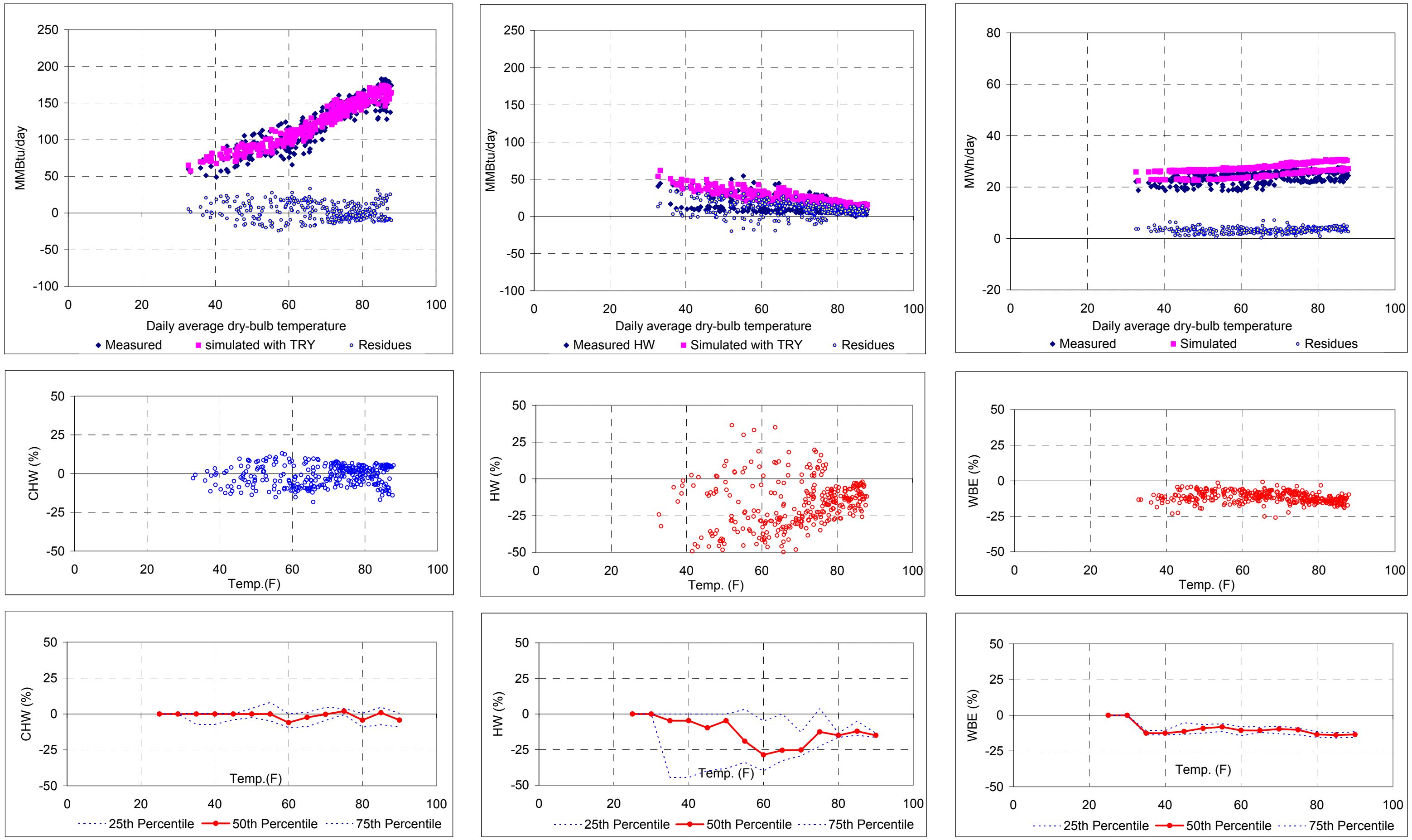


Figure 6.37 *Calibration signature after the 3rd run with undocumented air loss including exhaust air.*

6.2.4 The 4th Run: Heating Supply Air Temperature

A careful inspection of the measured data revealed that the boiler hot water supply and return temperature suddenly dropped at the end of July and then went back up in November during the period 3 as shown in Figure 6.38. Unfortunately, there is no keyword to control the hot water supply temperature for a boiler in DOE-2. Therefore, the hot deck air temperature for the AHUs was adjusted from 105 ^{o}F to 90 ^{o}F by proxy for the boiler hot water temperature change from 180 ^{o}F to 140 ^{o}F for the same operation period 3. As a result, the simulated heating energy was separated to two groups that more closely matched the measured data. Figure 6.39 and Figure 6.40 show the measured and simulated heating energy use before and after the hot deck air temperature adjustment.

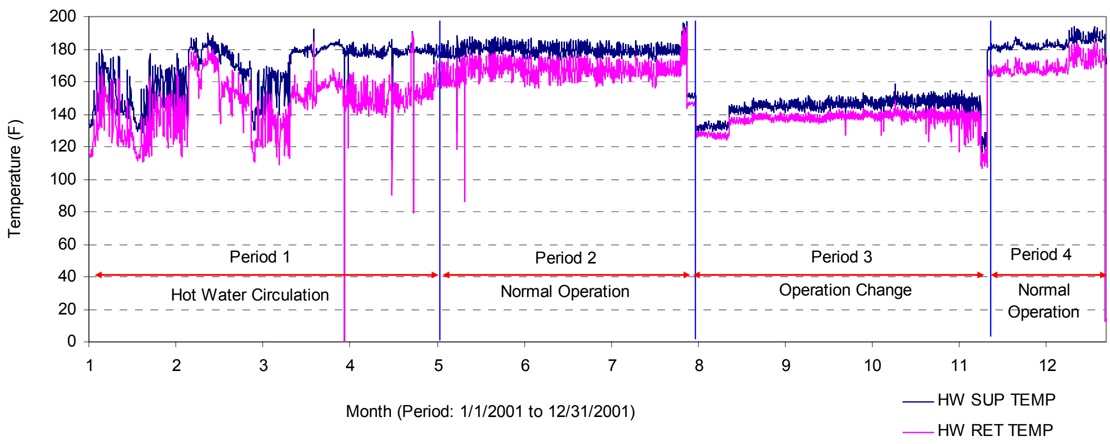


Figure 6.38 *Measured hourly HW supply and return temperature for 2001.*

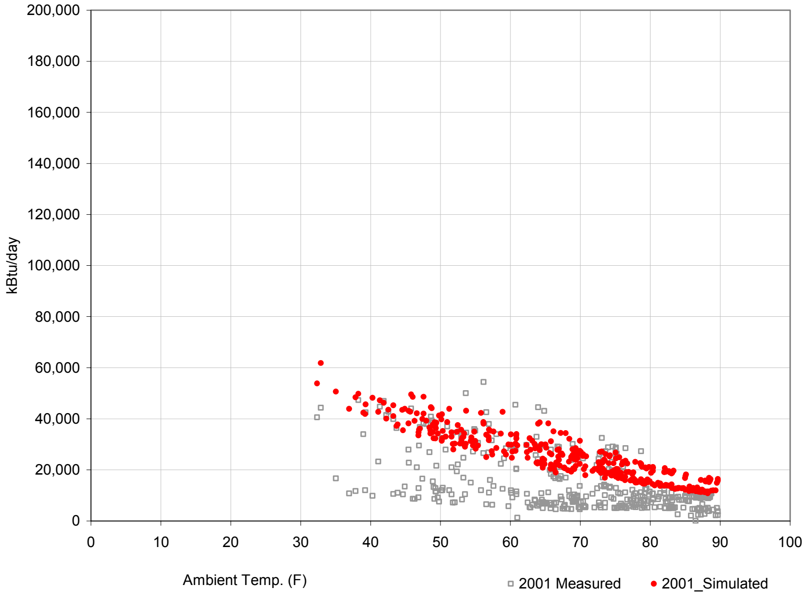


Figure 6.39 *Heating energy use before adjusting hot deck air temperature.*

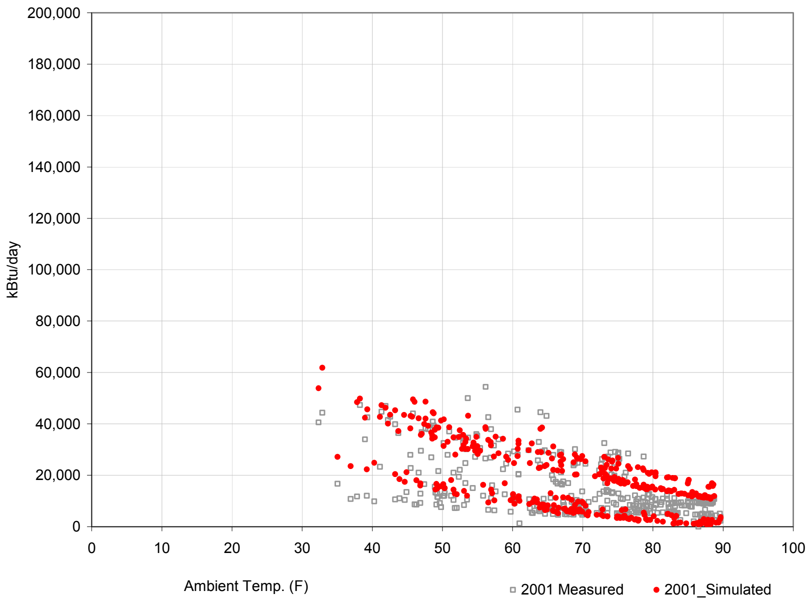


Figure 6.40 *Heating energy use after adjusting hot deck air temperature.*

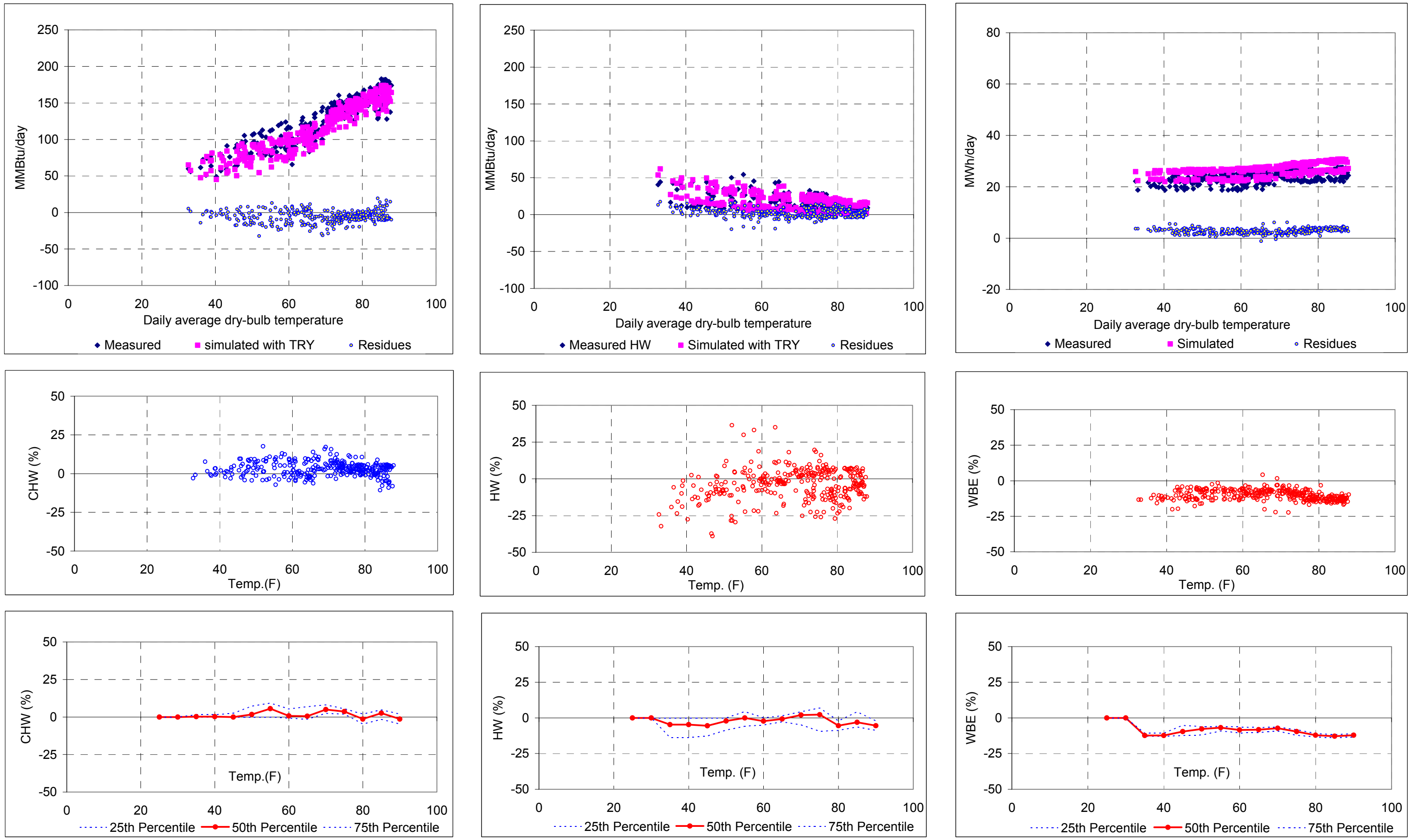


Figure 6.41 *Calibration signature after the 4th run with adjusted hot deck schedule.*

6.2.5 The 5th Run: Calculated Direct Normal Solar Radiation

During the course of this study, three packed weather files were developed using measured and calculated direct normal solar radiation as shown in Table 6.13. These files were then used to simulate the REJ as-built model for 2001 and 2004. Measured global horizontal solar radiation was used for both the 2001 and 2004 weather files. Unfortunately, measured direct normal solar radiation was no longer available in 2004 for this weather station due to funding cuts. Therefore, direct normal solar radiation was synthesized in this study using the Erbs correlation (Duffie and Beckman, 1991) for both 2001 and 2004 weather files, because the substitution of synthetic data in 2004 introduced significant changes to the direct normal component as shown in Table 6.13.

Table 6.13 Summary of Solar Radiation for 2001 and 2004 Weather File

Weather file	Global Horizontal Solar Radiation	Direct Normal Solar Radiation
2001	Measured	Measured
	Measured	Synthesized
2004	Measured	Synthesized

Figure 6.43 shows the time-series plot of the 2001 measured and calculated direct normal solar radiation, including a daily average residual plot that show a small positive bias. Figure 6.45 shows the residual of the direct normal radiation residual (measured–calculated). Overall, the measured direct normal solar radiation was higher when compared to the calculated data. Figure 6.44 is the time-series plot of the 2004 calculated direct normal solar radiation, which shows a similar pattern for the entire period of 2004 when compared to 2001. Consequently, it was found that there was a 2% increase in cooling energy and a 15% increase in heating energy when simulated using the TRY weather file packed with measured direct normal solar radiation. Therefore, both the 2001 and 2004 direct normal solar radiations were synthesized. Figure 6.45 and Figure 6.46 show the cooling energy use with residuals against dry-bulb temperature and global solar radiation, respectively. Figure 6.47 and Figure 6.48 show the heating energy use with residuals against dry-bulb temperature and global solar radiation, respectively. For the case-study building,

an increase of 5 MMBtu was observed for heating and cooling energy use for the whole simulation period. Figure 6.49 shows the calibration signature after the 5th run with calculated direct normal solar radiation.

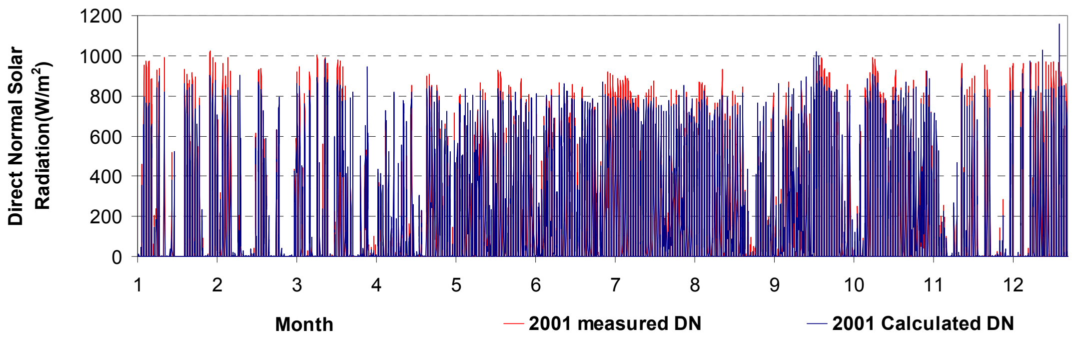


Figure 6.42 *Time-series plot of the 2001 measured and calculated direct normal solar radiation.*

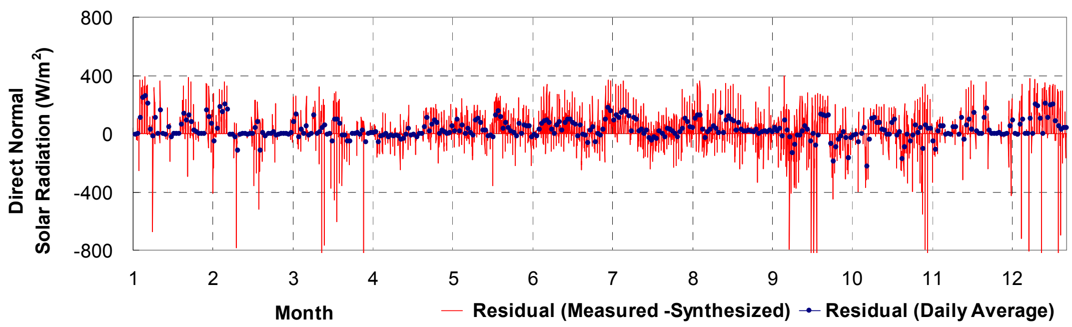


Figure 6.43 *Residual of the 2001 direct normal solar radiation (measured–calculated).*

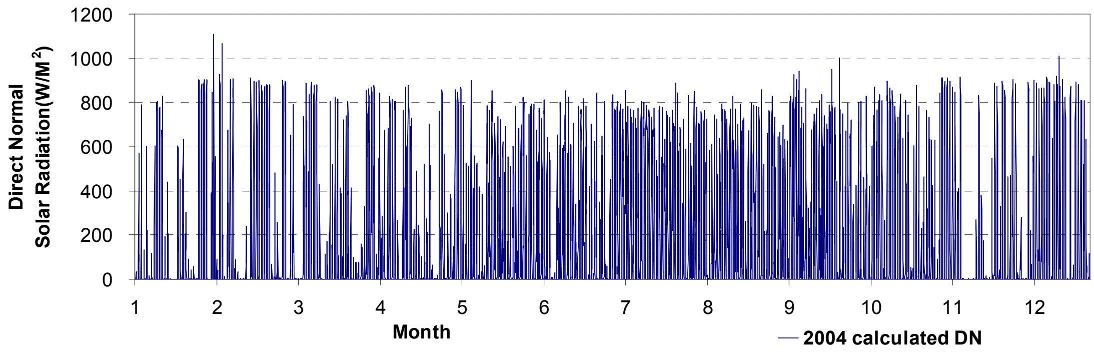


Figure 6.44 *Time-series plot of the 2004 calculated direct normal solar radiation.*

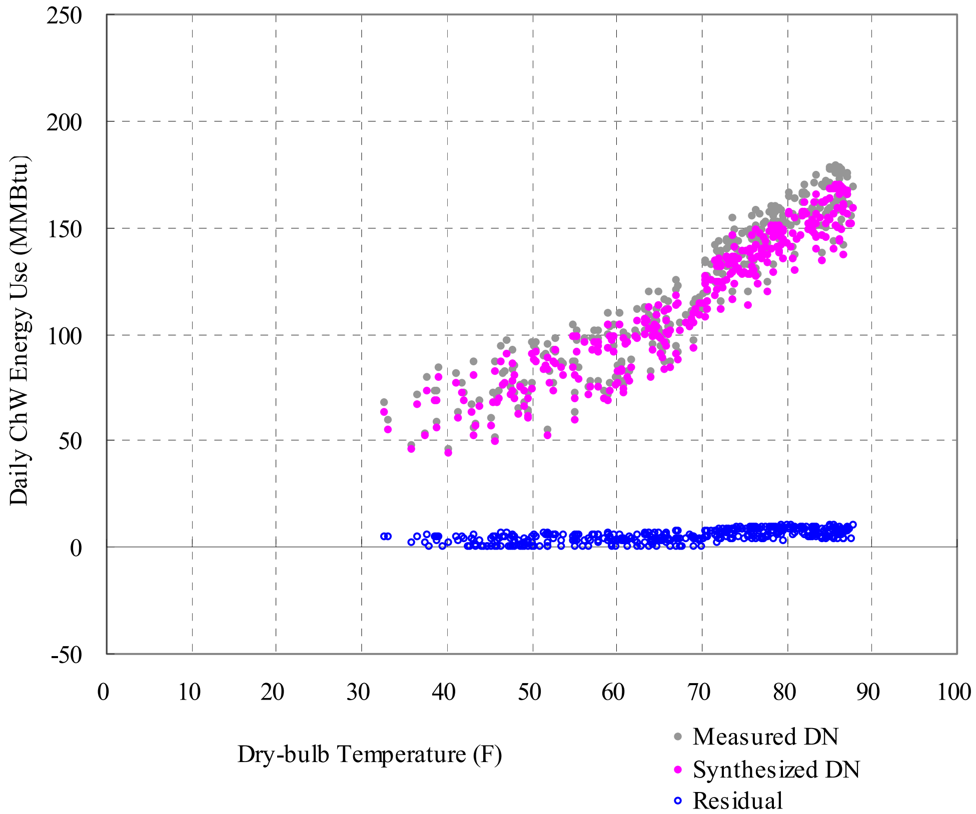


Figure 6.45 *Comparison of daily cooling energy and residual (measured DN-calculated DN) against dry-bulb temperature.*

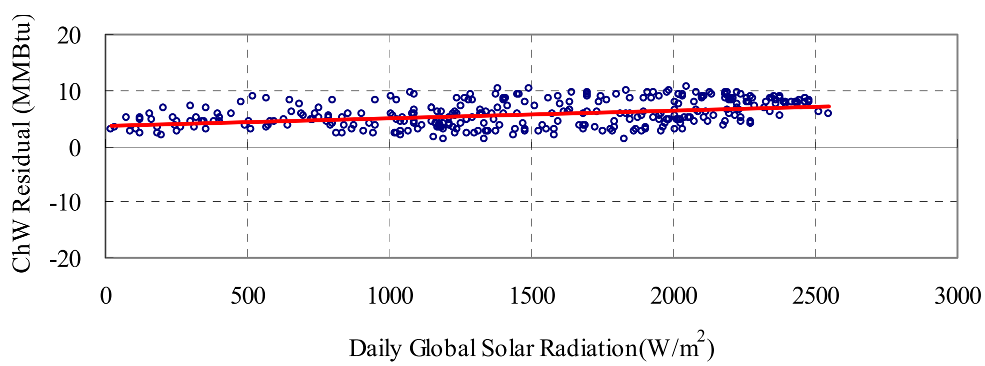


Figure 6.46 *Daily cooling energy residual (measured DN-calculated DN) against global solar radiation.*

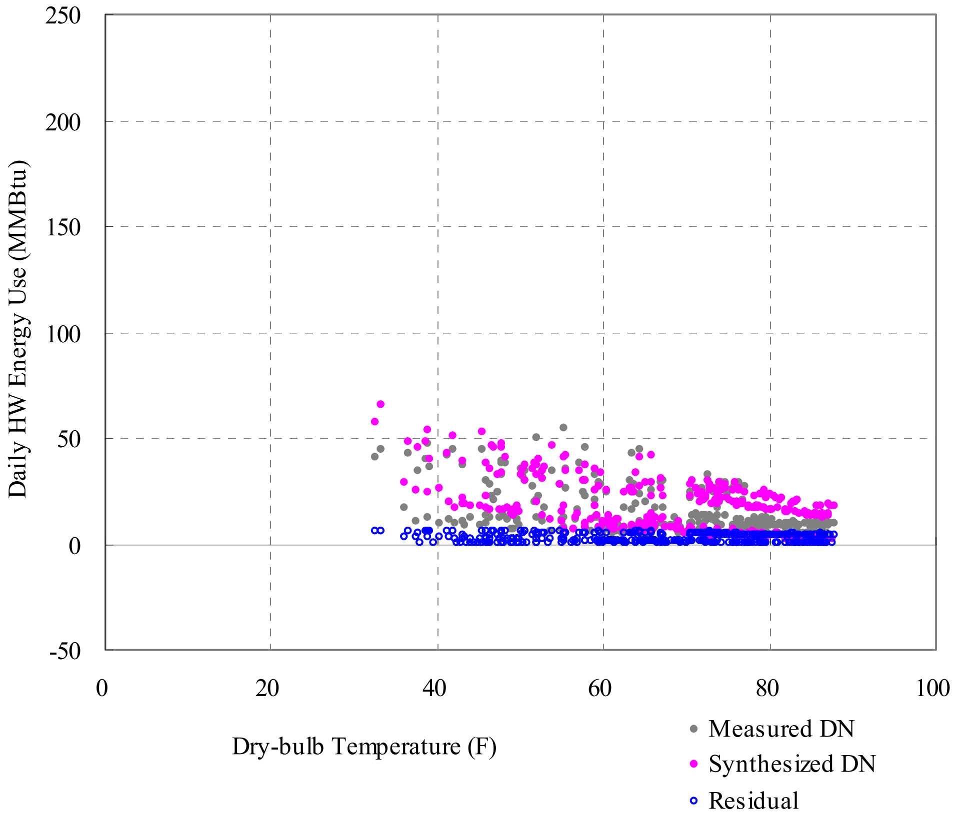


Figure 6.47 *Comparison of daily heating energy and residual (measured DN-calculated DN) against dry-bulb temperature.*

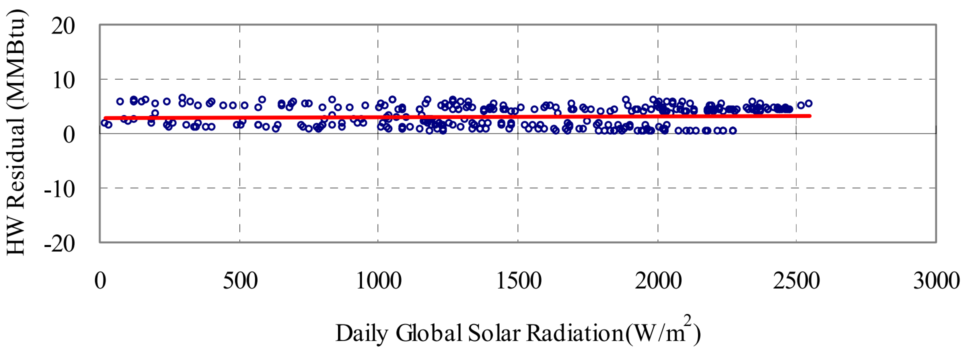


Figure 6.48 *Comparison of daily heating energy residual (measured DN-calculated DN) against global solar radiation.*

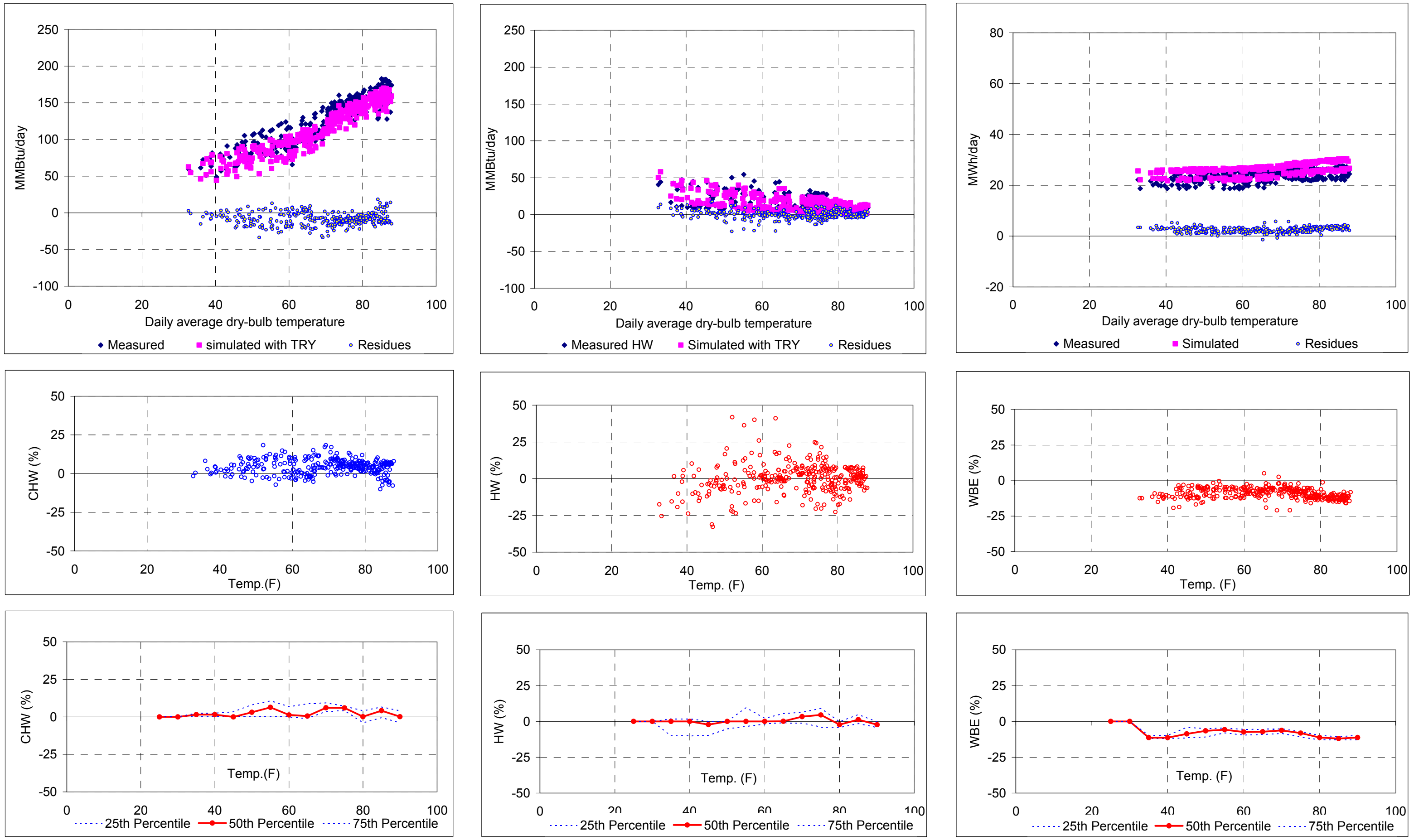


Figure 6.49 *Calibration signature after the 5th run with calculated direct normal solar radiation..*

6.2.6 Summary of 2001 Calibration Results

As described in Section 6.2, the 2001 as-built model was calibrated with measured data by changing the calibration factors cumulative to the base-model and analyzed the results with the characteristic signature plots. Table 6.14 summarizes the calibration results with cumulative calibration factors for each run. Figure 6.50 illustrates the building energy performance showing cumulated energy end-use in each run. Table 6.15 shows the statistical results with each calibration step. Figure 6.51 shows the overall CV(RMSE) and MBE in each run. Figure 6.52 and Figure 6.53 represent the CV(RMSE) and MBE in each run in terms of heating, cooling, and WBE, respectively. In the 1st calibration step, instead of an assigned CFM, the minimum supply air flow rate was set to 0.6 for the VAV systems, and the outside air flow rate was as a 10% in proportion to the total supply air flow for all the AHU systems. As a result, Overall CV(RMSE) and MBE were increased as shown in Figure 6.51, but CV(RMSE) for WBE was decreased slightly as shown in Figure 6.52. In the second run (i.e., Run 1+2), the CV(RMSE) for heating and cooling energy was decreased as expected with Custom Weighting Factors (CWFs), but not enough to reach an acceptable range as shown in Figure 6.52. For the third run (i.e., Run 1+2+3), a 30% of duct air loss was assumed to be about 20% of the total supply air flow and 10% of exhaust air from the building. As a result, cooling and heating energy use was increased significantly and had a good agreement with 9.49 CV(RMSE) and 1.75 MBE for the cooling loads as shown in Figure 6.52 and Figure 6.53. However, heating and electricity energy use needed further calibration. In the fourth run (i.e., Run 1+2+3+4), the hot deck air temperature for the AHUs was changed from 105 ^{o}F to 90 ^{o}F for the period that the boiler hot water temperature changed. As a result, the CV(RMSE) and MBE for heating energy was significantly decreased and overall CV(RMSE) also decreased to 19.69%. Finally, in the fifth run (i.e., Run 1+2+3+4+5) it was found that when simulated using the TRY weather file packed with measured direct normal solar radiation, overall CV(RMSE) was increased slightly to 20.38%, but MBE was decreased to 0.63%. The calibration model was finally determined to have overall 20.38% CV(RMSE) and a 0.63% MBE for the 2001 model.

Table 6.14 DOE-2 Calibration and Results with Each Run

Models / Category of Use	Base Model	Run1	Run2 (Run 1+2)	Run3 (Run 1+2+3)	Run4 (Run 1+2+3+4)	Run5 (Run 1+2+3+4+5)
	Assigned CFM	10% OA	Custom Weighting	30% of Duct Air Loss	Max. Supply Air Temp.	Direct Normal Solar Radiation
AREA LIGHTS	7294.4	7294.4	7294.4	7294.4	7294.4	7294.4
MISC EQUIPMT	8458.8	8458.8	8458.8	8458.8	8458.8	8458.8
SPACE HEAT	9862.5	6689.2	9795.6	13492.7	9765.5	8595.7
SPACE COOL	6225.5	4758.5	5032.1	7118.1	6780.1	6659.7
HEAT REJECT	296.8	283.4	290.7	404.2	383.2	372.5
PUMPS & MISC	991.2	774.9	773.4	796.7	796.6	796.8
VENT FANS	6258.1	4552.7	4837.8	6911.7	6887.9	6694.9
DOMHOT WATER	115.3	115.3	115.3	115.3	115.3	115.3
EXT LIGHTS	2177.0	2177.0	2177	2177.0	2177.0	2177.0
Total (MMBtu)	41679.6	35104.2	38775.1	46768.9	42658.8	41165.1
Total (kBtu/sqft-yr)	135.3	114.0	125.9	151.9	138.5	133.7

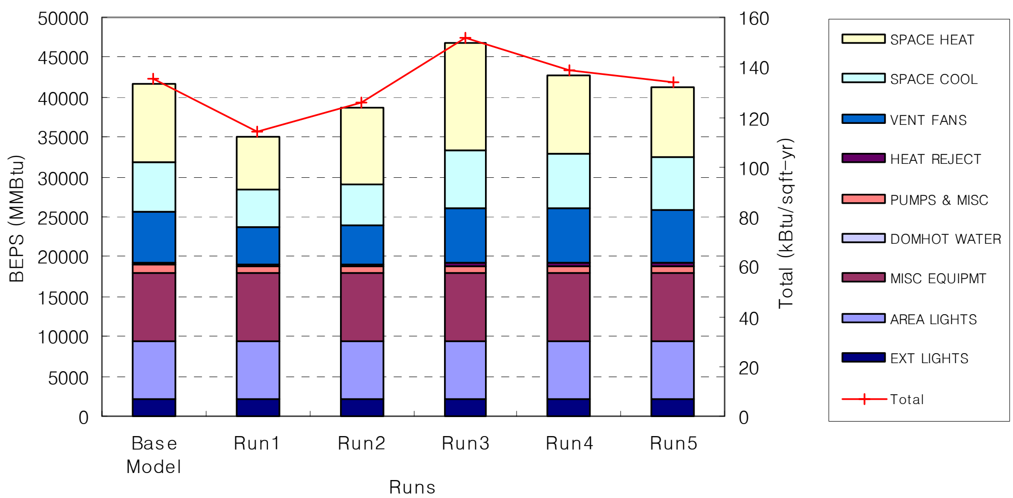


Figure 6.50 *DOE-2 calibration results with each run for 2001 calibration.*

Table 6.15 Summary of Statistical Results in Each Run

Runs	Daily MBE (%)			Daily CV(RMSE) (%)			Overall (%)	
	Cooling	Heating	WBE	Cooling	Heating	WBE	MBE (%)	CV(RMSE) (%)
0	-38.62	20.29	7.63	40.94	58.85	8.84	-3.57	36.21
1	-49.49	-22.98	-3.84	53.04	82.35	6.01	-25.44	47.13
2	-41.05	19.26	-2.32	44.61	55.49	5.07	-8.04	35.06
3	1.75	42.08	11.93	9.49	58.18	12.52	18.59	26.73
4	-4.85	12.92	10.50	8.55	39.38	11.13	6.19	19.69
5	-7.01	-0.60	9.51	10.31	40.62	10.22	0.63	20.38
N-1	321.00	321.00	359.00	321.00	321.00	359.00	-	-

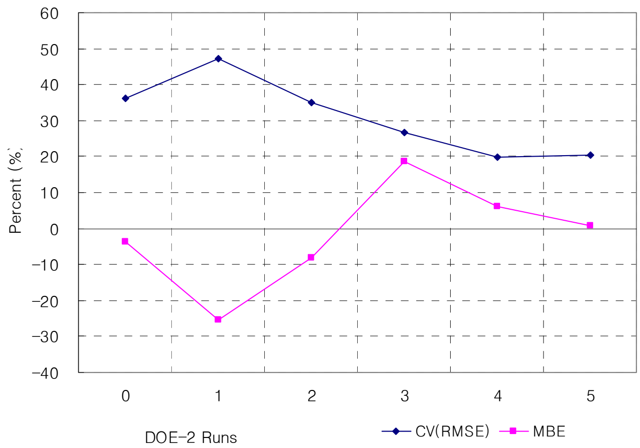


Figure 6.51 *Overall MBE and CV(RMSE) with each calibration step.*

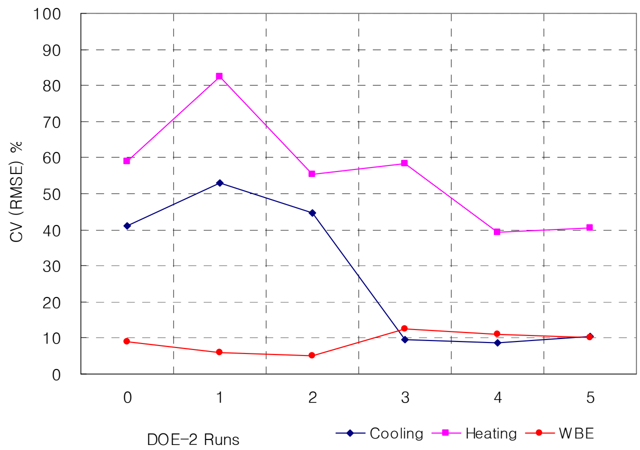


Figure 6.52 *CV(RMSE) for heating, cooling, and WBE for each run.*

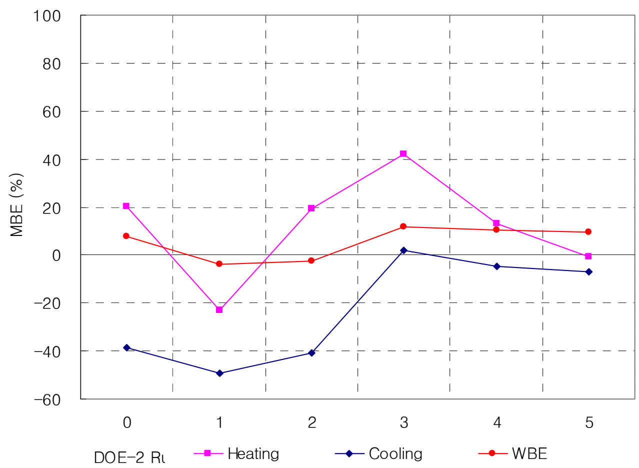


Figure 6.53 *MBE for heating, cooling, and WBE for each run.*

6.3 2004 As-built Model Calibration

This Section describes the 2004 as-built model calibration and results for each run. As a base model, the 2001 calibrated as-built simulation model described in the previous Chapter VI, Section 6.2 was used and then calibrated with 2004 measured data by adjusting 2004 lighting and receptacle schedules and operational changes. Calibration signatures for heating, cooling, and electricity were also developed in this study to further calibrate the model until the simulated results matched with the 2004 measured data at acceptable graphical and statistical levels. Table 6.16 shows the factors used for the 2004 calibration in each run, including: (1) Weather data file (2) 2004 Internal load and schedule, (3) Max supply air temperature, (4) Hot deck and cold deck air temperature, (5) Chiller operation, and (6) Preheat temperature.

Table 6.16 DOE-2 Calibration Factors in Each Run for 2004 Calibration

Calibration Factors		Base Model	Run1	Run2	Run3	Run4
1	Weather Data File	2001	2004	2004	2004	2004
2	Internal Loads and Schedule	2001	2004	2004	2004	2004
3	Max. Supply Temperature	105	95	75	85	85
4	Hot Deck Temperature	105	95	90/75	75/72/95/80/75	75/72/95/80/75
5	Cold Deck Temperature	55	55	55/50	55	55
6	Chiller Operation	Parallel	Parallel	Parallel	Parallel	Sequence
7	Preheat Temperature	45	45	45	45	60

Figure 6.54 illustrates the calibration signatures developed from the 2001 calibrated as-built base model. The calibration signatures indicate that simulated cooling use against dry-bulb temperature is similar to the 2004 measured data, but heating energy use has differences up to 150% due to operational changes. Simulated electricity use should also reduce overall temperature. In the following Section, calibration methods and results are described in detail for each calibration step.

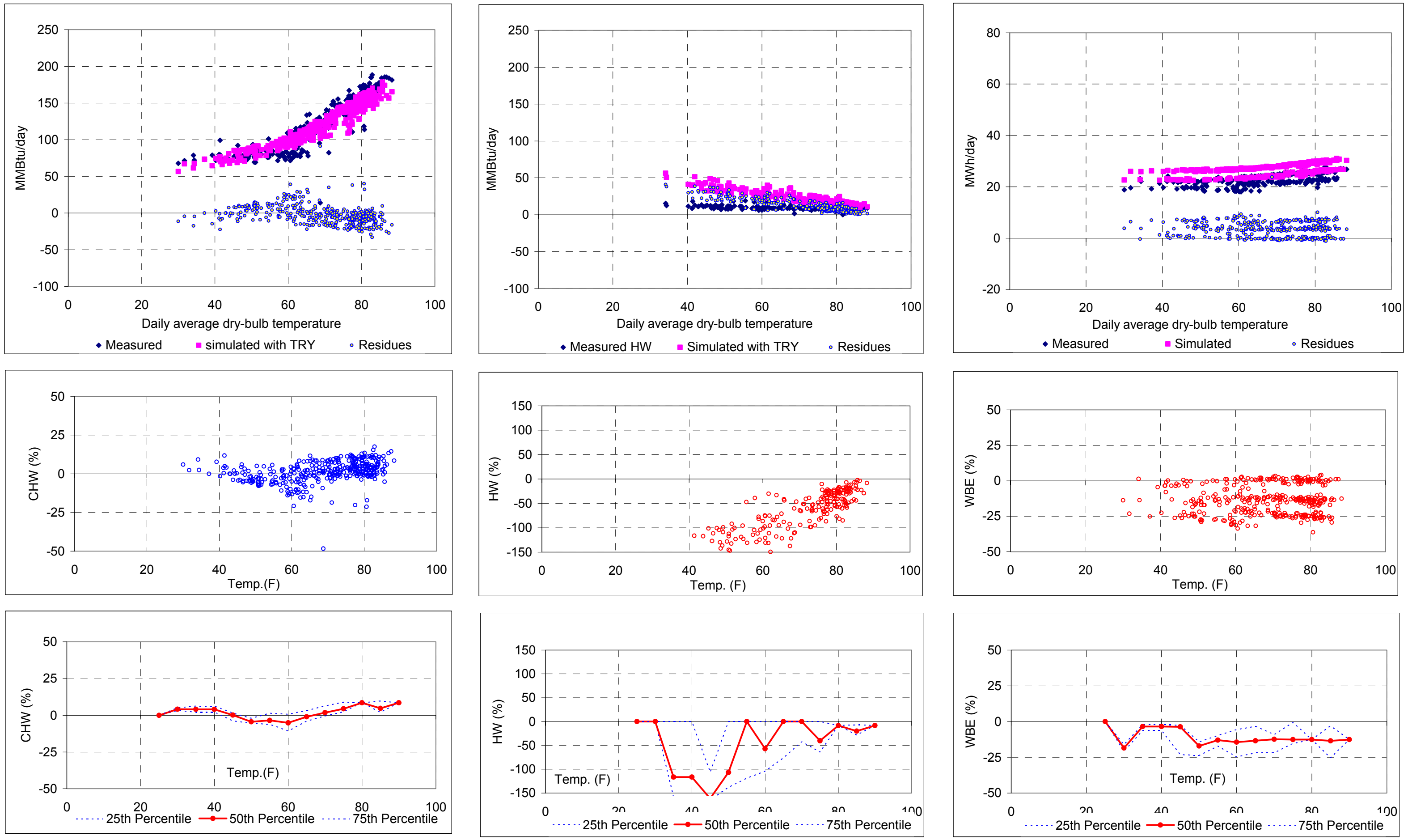


Figure 6.54 *Calibration signature of the 2004 as-built base model simulation..*

6.3.1 The 1st Run: 2004 Packed Weather File

For the first calibration effort, a 2004 weather file was packed to the TRY format with calculated direct normal solar radiation and then simulated with the same as-built base model. The results show that the whole-building electricity (WBE) use had an agreement with the measured data after the 1st run. Figure 6.55 shows the Calibration Signature after the 1st run with the 2004 Packed Weather Data. The results show that the total energy use was decreased, but the calibration signature was improved only slightly, which indicates that the 2004 weather conditions were similar to the 2001 weather conditions.

6.3.2 The 2nd Run: Hot Deck Air Temperature

A measured heating energy use was divided into two groups similar to the 2001 heating energy use, which indicated that there were operation changes for both 2001 and 2004. For the heating energy calibration, the hot deck air temperature was set to 90 ^{o}F and 75 ^{o}F according to the period of heating energy change as described in Chapter V, Section 5.4. Consequently, the signature of the heating energy use was significantly improved, but still needed adjustment as shown in Figure 6.56.

6.3.3 The 3rd Run: Hot Deck, Cold Deck, and Max. Supply Air Temperature

In the 3rd run, the hot deck temperature was scheduled to further calibrate the simulation with the measured data. The max supply temperature was also set to 85 ^{o}F from 75 ^{o}F. Figure 6.57 shows the calibration signature after the 3rd run with adjusted max supply air temperature and hot and cold deck temperature schedule. Heating energy use was significantly improved, but cooling energy use worsened.

6.3.4 The 4th Run: Chiller Operation

In the 4th run, the chiller operation was changed to a sequence mode from a parallel operation at the part-load condition and the preheat temperature was also increased from 45 ^{o}F to 60 ^{o}F. Figure 6.58 shows the calibration signature after the 4th run with sequence chiller operation and the adjusted preheat temperature. The results show that there was little change after the 4th run for heating, cooling, and electricity use.

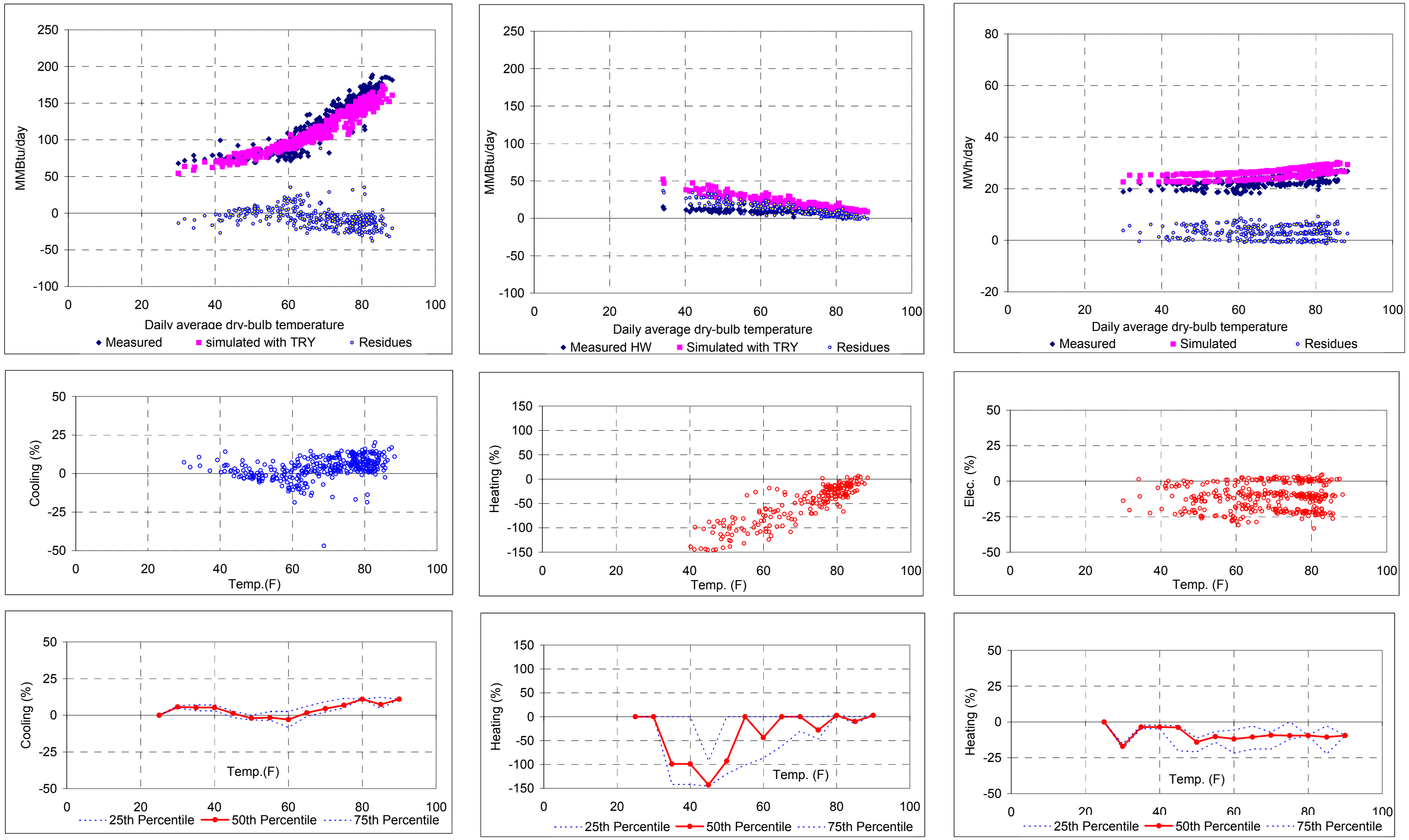


Figure 6.55 *Calibration signature after the 1st run with the 2004 packed weather file.*

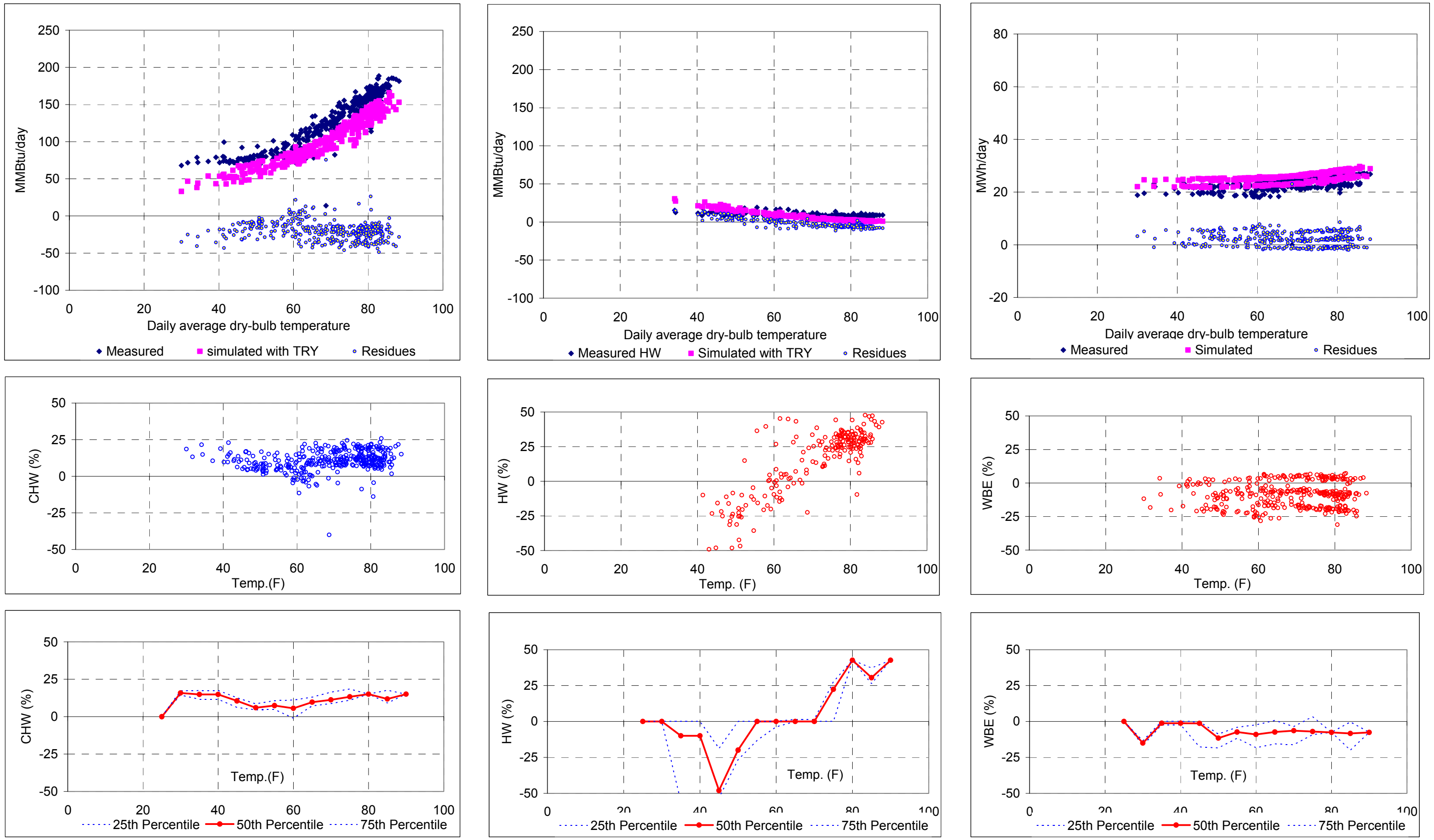


Figure 6.56 *Calibration signature after the 2nd run with adjusted max supply temperature, and hot and cold deck temperature schedule.*

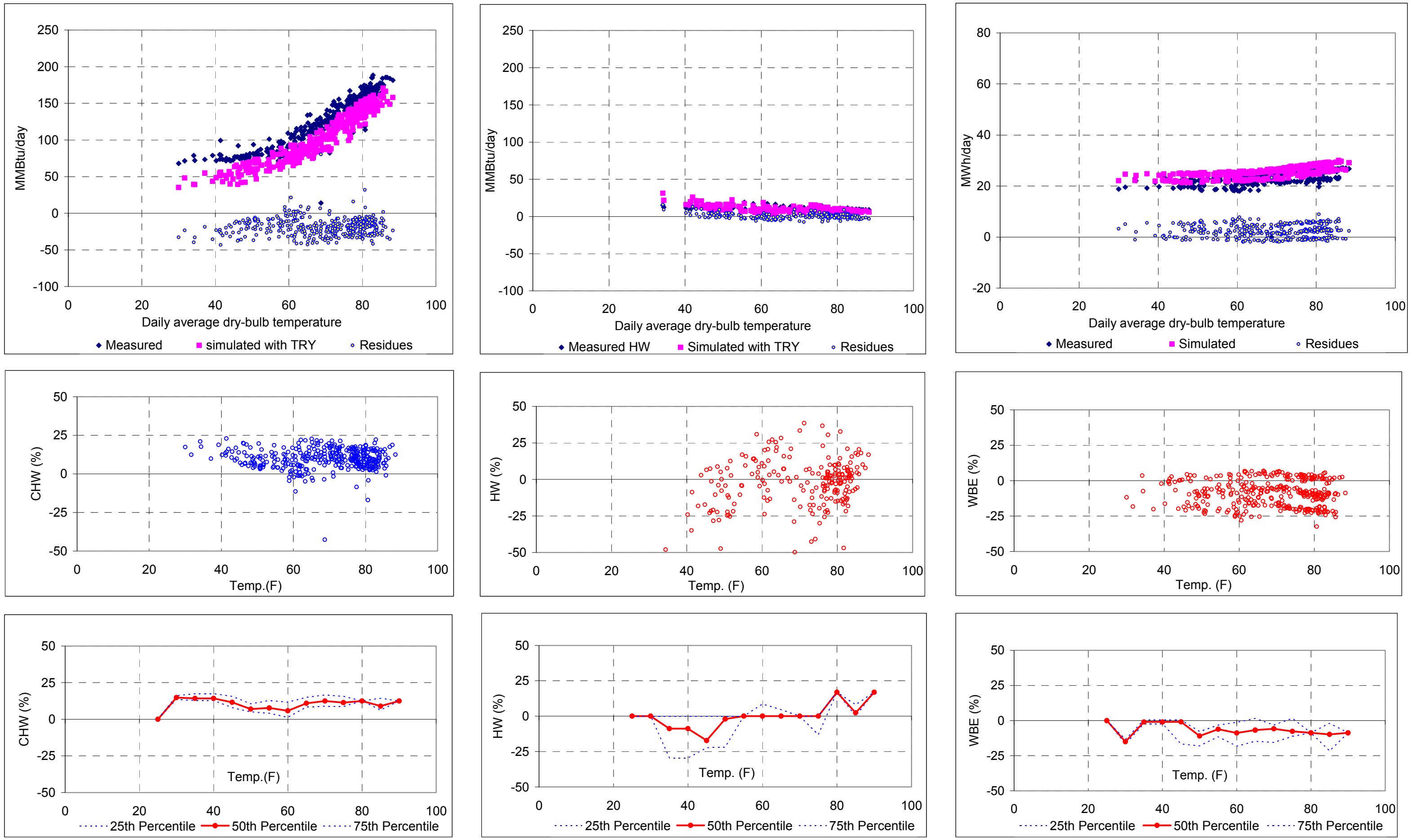


Figure 6.57 *Calibration signature after the 3rd run with adjusted Max supply temperature, and hot and cold deck temperature schedule.*

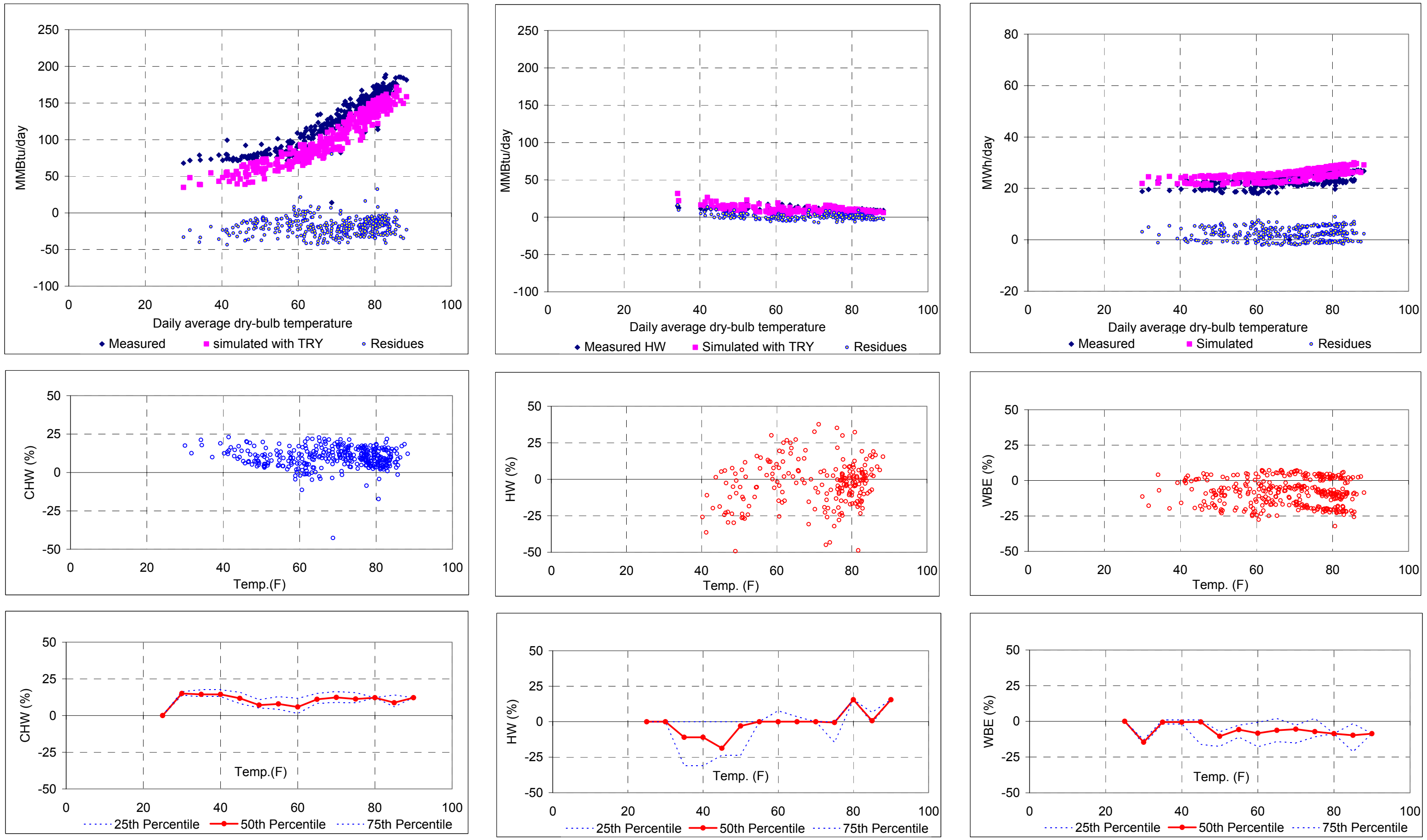


Figure 6.58 *Calibration signature after the 4th run with adjusted hot deck temperature schedule and chiller operation..*

6.3.5 Summary of 2004 Calibration Results

Table 6.17 summarizes the building energy performance with each run for the DOE-2 calibration, and Figure 6.59 illustrates the end-use results in each run. Table 6.18 shows the statistical results with each calibration step. Figure 6.60 shows the overall CV(RMSE) and MBE in each run. Figure 6.61 and Figure *6.62* represent the CV(RMSE) and MBE in each run in terms of heating, cooling, and WBE, respectively. For the first calibration effort, a 2004 weather file was packed to the TRY format with calculated direct normal solar radiation and then simulated with the same as-built base model. The results show that the whole-building electricity (WBE) use had an agreement with the measured data after the 1st run. For the heating energy calibration, the hot deck air temperature was set to 90 ^{o}F and 75 ^{o}F according to the period of heating energy change as described in Chapter V, Section 5.4. Consequently, the signature of the heating energy use was significantly improved, but still needed adjustment as shown in Figure 6.56. In the 3rd run, the hot deck temperature was scheduled in additional detail to better calibrate with the measured data. The max supply temperature was also set to 85 ^{o}F from 75 ^{o}F. Heating energy use was significantly improved, but cooling energy use worsened. In the 4th run, the chiller operation was changed to a sequence mode from a parallel operation at the part-load condition and the preheat temperature was also increased from 45 ^{o}F to 60 ^{o}F. The results show that there was little change after the 4th run for heating, cooling, and electricity use.

Table 6.17 2004 DOE-2 Calibration and End-use Results with Each Run

Category of Use	Base Model	Run1	Run2	Run3	Run4
AREA LIGHTS	7294.4	7219.1	7219.1	7219.1	7219.1
MISC EQUIPMT	8458.8	8339.4	8339.4	8339.4	8339.4
SPACE HEAT	12540.9	10977.4	3820.7	4775.6	4918.7
SPACE COOL	7039.7	6820.4	6199.3	6301.1	6308.1
HEAT REJECT	392.2	370	339.4	350.6	351.7
PUMPS & MISC	804.4	790.5	790.3	790.4	581
VENT FANS	6836.1	6580.7	6571.7	6545.8	6598.7
DOMHOT WATER	115.3	115.3	115.3	115.3	115.3
EXT LIGHTS	2177	2177	2177	2177	2177
Total (MMBtu)	45658.8	43389.8	35572.2	36614.3	36609
Total (kBtu/sqft-yr)	148.3	140.9	115.5	118.9	118.9

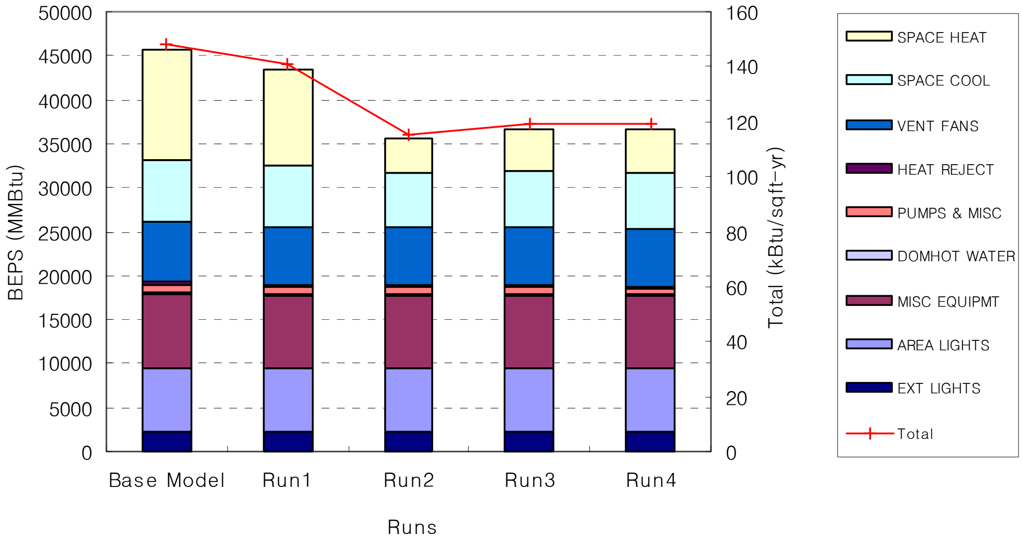


Figure 6.59 *2004 DOE-2 calibration results with each run.*

Table 6.18 Summary of Statistical Results in Each Run

Runs	Daily MBE (%)			Daily CV(RMSE) (%)			Overall (%)	
	Cooling	Heating	WBE	Cooling	Heating	WBE	MBE (%)	CV(RMSE) (%)
0	-1.99	60.76	14.03	11.10	72.98	17.79	24.26	33.96
1	-5.98	54.62	12.03	12.87	69.89	15.81	20.22	32.86
2	-19.25	-34.53	9.40	22.96	88.64	14.25	-14.80	41.95
3	-17.41	6.35	9.76	20.96	36.33	14.46	-0.43	23.92
4	-17.28	9.16	9.36	20.87	36.35	14.24	0.41	23.82
N-1	321.00	321.00	359.00	321.00	321.00	359.00	-	-

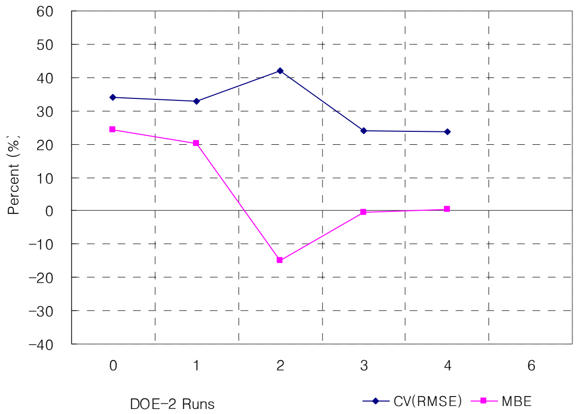


Figure 6.60 *Overall 2004 MBE and CV(RMSE) with each calibration step.*

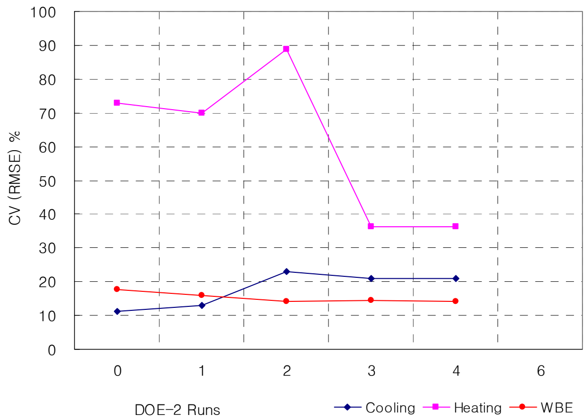


Figure 6.61 *2004 CV(RMSE) for heating, cooling, and WBE with each run.*

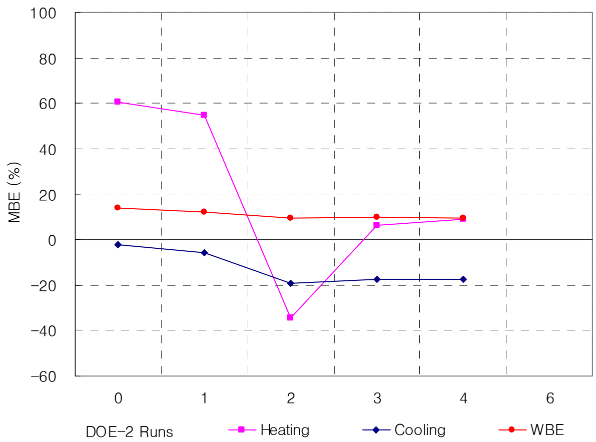


Figure 6.62 *2004 MBE for heating, cooling, and WBE with each run.*

6.4 Summary of the As-built Simulation and Calibration

Three different as-built simulation models were developed in this study. The 2001 as-built model was first developed based on as-built design conditions, and then it was calibrated with 2001 measured data for evaluating energy performance compared to the energy baselines. The 2004 calibrated as-built model was also developed to evaluate the potential energy savings from the proposed improvements. Then, a detailed simulation and calibration was performed based on the methods with significant calibration factors applicable to new buildings, including: weather data packed to TRY format, typical loads day-typing, Custom Weighting Factor Method (CWF) with U-effective calculation, low-e window library using Window 5.2, HVAC systems performance, and enhanced signature methods with percentile analysis. Consequently, the calibrated models were determined to have an overall 20.38% CV(RMSE) and a 0.63% MBE for the 2001 model and 23.82% CV(RMSE) and a 0.61% MBE for the 2004 model. The calibration results compare well with previous research for a new building, which had a 23.1% CV(RMSE) and a -0.7% MBE by Bou-Saada (1994). According to the ASHRAE Guideline 14 (2000) pp. 41, 'Models are declared to be calibrated if they produce NMBE with ±10% and CV(RMSE) within ±30% when using hourly data, or 5% or 15% with monthly data'.

CHAPTER VII

RESULTS: ENERGY PERFORMANCE EVALUATIONS

The Robert E. Johnson (REJ) state office building in Austin, Texas was designed to be a sustainable design project using various Energy Conservation Design Measures (ECDMs) as defined in the report by Eley (Eley and Tathagat 1998). To assess the energy performance of the REJ building, several comparisons were used, including: an Energy Use Index (EUI) comparison, comparison against ASHRAE Standard 90.1-1989 and Standard 90.1-2001, and an evaluation of the performance of specific ECDMs. Each of the comparisons is discussed in the following Sections.

7.1 Comparison of Energy Baselines

7.1.1 EUI Comparison with Similar Buildings

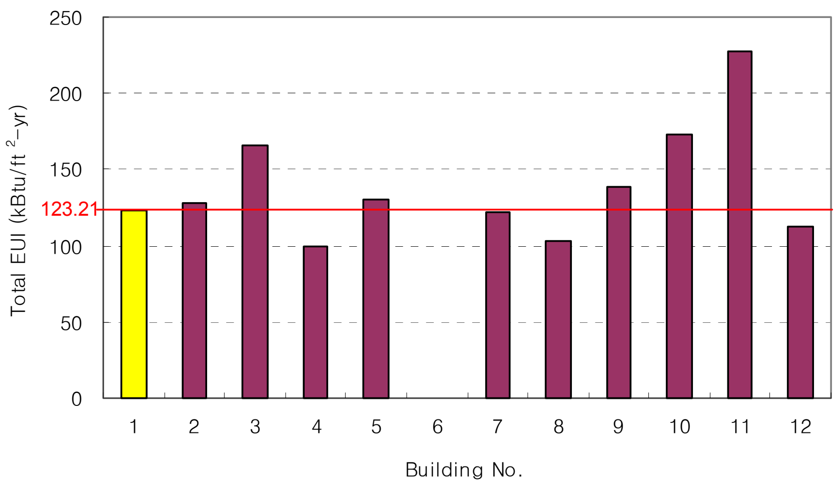
The Energy Use Indices (EUIs) measured from the case-study building were compared with similar buildings (Haberl et al., 2001) in Austin, Texas. Table 7.1 shows the EUIs for similar buildings in a control group, in terms of whole-building electricity (WBE), Motor Control Center (MCC), Lighting and Receptacles (WBE-MCC), Whole-building Cooling (WBC), Whole-building Heating (WBH), and Total Energy Use Indices (EUIs). The EUIs for the REJ building were derived from the diversity factors as discussed in Chapter IV, Section 4.2.

Table 7.1 Energy Use Indices (EUIs) for Similar Buildings in Austin, Texas

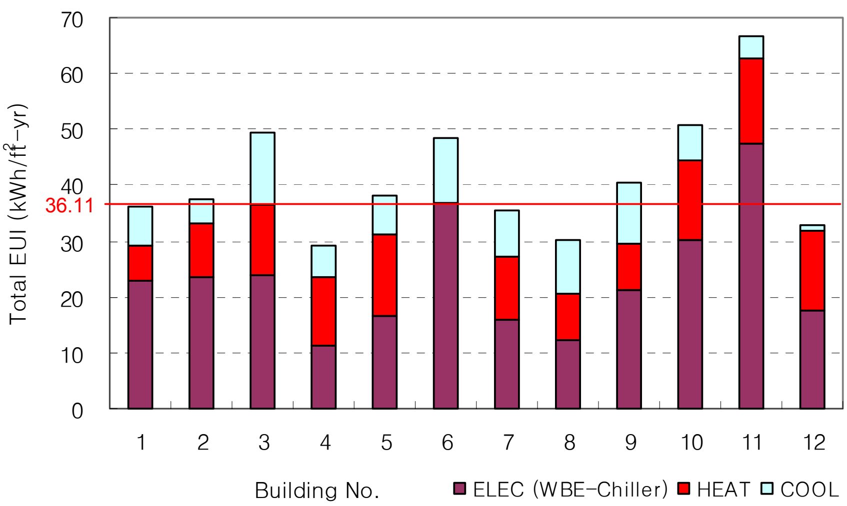
No.	Building Name	Building Area(ft^2)	Period	Whole-building EUI (kWh/ft2-yr)					
				WBE	MCC	WBE-MCC	WBC	WBH	Total
1	REJ building	303,389	2001	29.85	9.09	20.76	7.08	6.26	36.11
2	John H. Reagan	169,746	1997	23.63	2.41	21.22	4.49	9.43	37.55
3	Insurance	102,000	1996	24.00	4.89	19.04	12.74	12.61	48.75
4	Archives	120,000	1997	11.25	3.81	7.44	5.74	12.29	29.29
5	W.B. Travis	491,000	1997	16.53	0.22	16.31	7.23	14.53	38.29
6	L.B. Johnson	308,080	1997	36.70	3.05	33.66	11.68	-	-
7	Price Daniels	151,620	1998	15.86	-	-	8.55	11.23	35.65
8	Tom C. Clark	121,654	1998	12.31	-	-	9.58	8.34	30.23
9	Capitol	282,499	1998	21.08	-	-	10.87	8.54	40.49
10	Sam Houston	182,961	1993	30.13	-	-	6.32	14.31	50.77
11	James E. Rudder	80,000	1994	47.53	-	-	3.74	15.33	66.60
12	Insurance Annex	62,000	1993	17.63	2.46	15.17	1.05	14.31	32.99

(Source: Haberl et al., 2001).

As shown in Table 7.1 and Figure 7.2, the total EUI of the REJ building was measured to be 123.21 kBtu/ft^2-yr (36.11 kWh/ft^2-yr), which compares well with the John H. Reagan building (No. 2), the W.B. Travis building (No. 5), the Price Daniels building (No. 7), and the Capitol building (No.9), all of which are considered to be average energy users. In the lower portion of Figure 7.1, the total EUIs are broken down into heating, cooling, and electricity use (i.e., whole-building electric minus chiller electric). These end-use EUIs provide additional information that begins to explain the difference in energy use.



a) Total EUIs



b) Total EUI with sub-metered data

Figure 7.1 *Comparison of total EUIs for similar buildings.*

Figure 7.2 shows weather-independent lighting and receptacle (L&R) electricity EUI along-side the whole-building electricity (WBE) EUI. The L&R electricity EUI of the REJ building is similar to the Reagan (No.2) and Insurance (No.3), which possible would indicate as being high internal loads. The L&R electricity EUI was calculated by subtracting the Motor Control Center (MCC) EUI from the WBE EUI. In Figure 7.2 and Figure 7.3, the REJ building showed significant MCC Electricity EUI compared to other buildings.

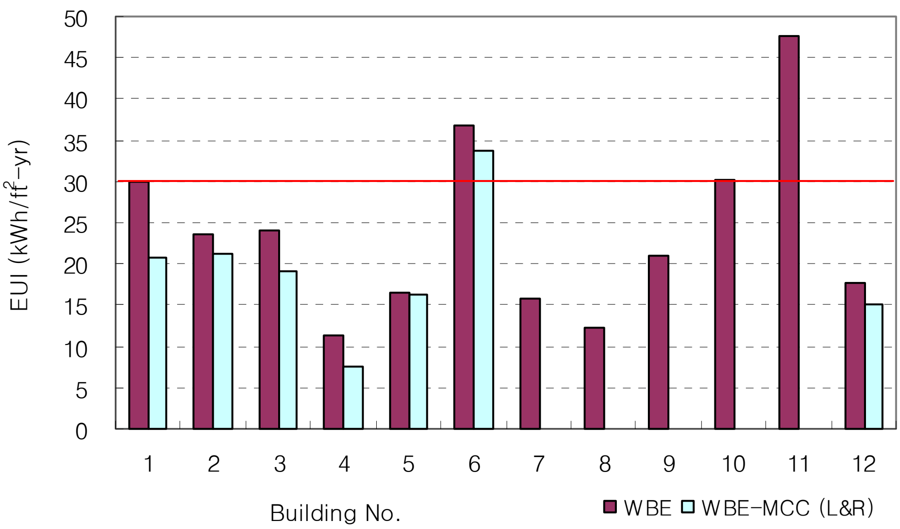


Figure 7.2 *Comparison of WBE-MCC electricity EUI for similar buildings.*

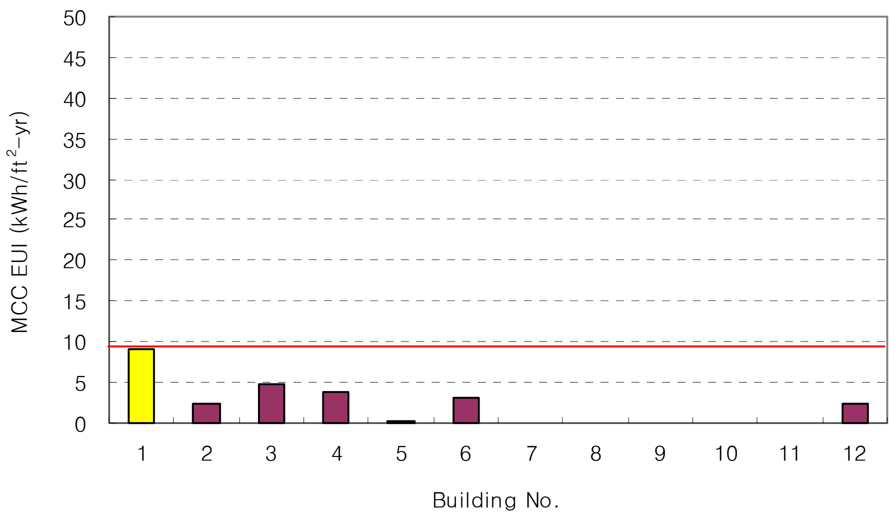


Figure 7.3 *Comparison of MCC electricity EUI for similar buildings.*

Table 7.4 and Table 7.5 show the whole-building heating (WBH) EUIs and cooling (WBC) EUIs, respectively. The REJ building seems to be more efficient in terms of heating energy use than cooling energy use when compared to other similar buildings in Austin, Texas. On the other hand, the heating energy use of the REJ building in Figure 7.4 is less than all four other buildings (i.e., No. 2, 3, 5, and 9). Cooling energy use is about average.

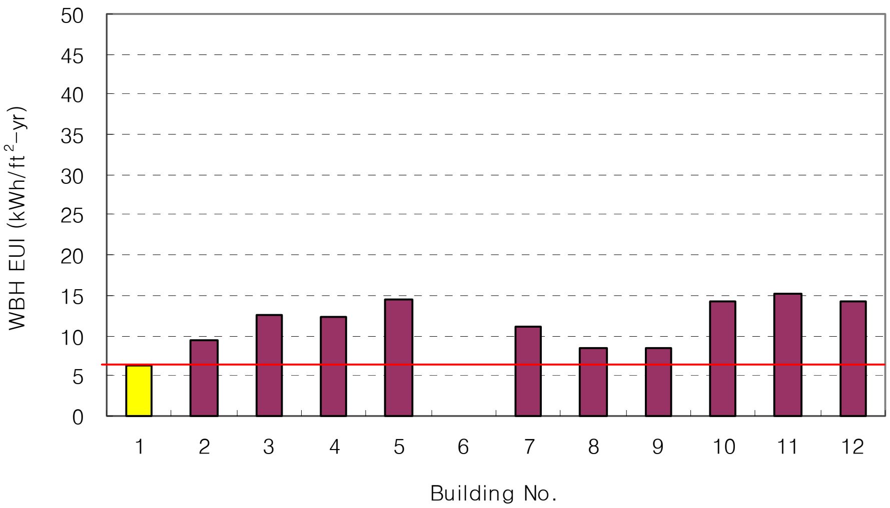


Figure 7.4 *Comparison of WBH EUI for similar buildings.*

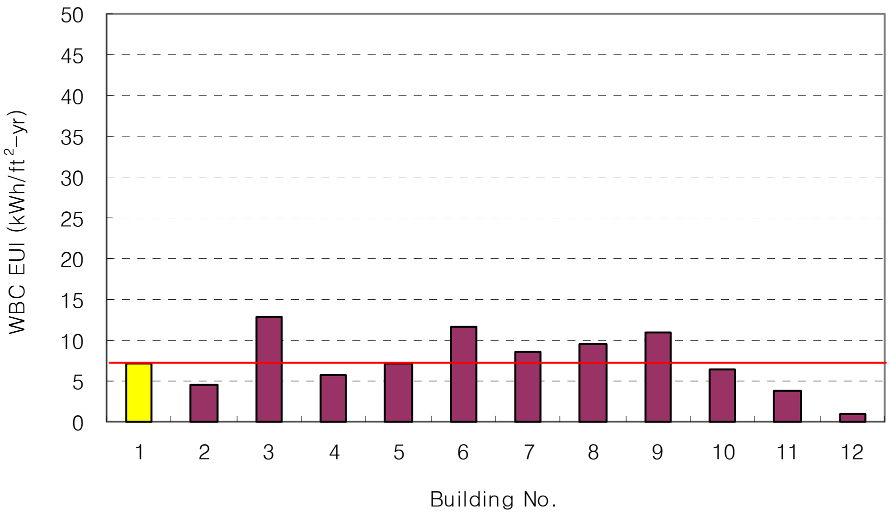


Figure 7.5 *Comparison of WBC electricity EUI for similar buildings.*

In summary, the use of the WBE EUI comparisons are of limited use because it may contain significant amounts of energy use from special purpose equipment, such as print center and office equipment, which can mask the cooling or heating efficiencies. On the other hand, the end-use EUIs, such as cooling, heating, and MCC use can begin to provide some information about the building's heating and cooling efficiencies, although this remains of limited use in determining the actual performance of the building's systems because too many unknowns remain in the EUIs. In the following Sections, energy savings are discussed in detail using calibrated as-built simulation compared to the Standard 90.1-1989 and 2001 code baselines and the base-case building that has the same shape and function, but doesn't include the ECDMs as the REJ building.

7.1.2 Comparison of the Standard 90.1-1989 and 2001 Code Baselines

As discussed in Chapter IV, Section 4.3, the 2001 calibrated as-built simulation was used to evaluate the energy performance compared to code baselines and the base-case model. Table 7.2 shows the simulation parameters for the Standards 90.1-1989 and 2001 code baselines used in this study. To calculate actual energy savings compared to the code baselines, the same building schedules and system controls as the 2001 as-built model were applied to the code baselines, as shown in Table 7.3. Each model for the Standard 90.1-1989 and 2001 was developed with two different window-to-wall ratio (15% vs. 51.45%) and AHU systems types (SZRH vs. DDVAV). Table 7.4 and Figure 7.6 compare the simulation results for each model. As expected, the Standard 90.1-1989 building (i.e., 89model 2) consumed more heating energy than the Standard 90.1-1989 (i.e., 89model 1) due to high window-to-wall ratio. For the Standard 90.1-2001 models, a single-zone reheat system (SZRH) and dual-duct variable air volume (DDVAV) were applied to the same 2001 code baseline. As a result, the Standard 90.1-2001 (i.e., 01 model 1) consumed more heating energy than the Standard 90.1-2001 (01model 2), which is the same as the as-built model. Figure 7.7 shows the annual energy end-use for each code model. Overall, the Standard 90.1-1989 building (i.e., 89model 2) consumed the highest heating, cooling, and vent fan energy due to the high window-to-wall ratio (51.45%), which is the same window-to-wall ratio as the as-built model, but not compliant with the Standard 90.1-1989. In order to calculate actual energy savings, the first models (i.e., 89 model 1 and 01 model 1) from each code were selected in this study as code baselines compliant with the Standard 90.1-1989 and 2001 models. The Standard 90.1-1989 building (i.e., 01 model 1) defined 15% of window-to-wall ratio from the ACP Table 8A-12 as described in Chapter IV, Section 4.3.2, while the Standard 90.1-2001 building (i.e., 01model 1) defined the same window-to-wall ratio (51.45%) and AHU systems types (DDVAVs) as the as-built model.

Table 7.2 DOE-2 Simulation Parameters for the Standard 90.1 -1989 and 2001 Models

No.	Items		1989 Budget Model	2001 Budget Model	Calibrated As-built Model	Remarks
	Building shape		Rectangular(2.5: 1)	As-built	As-built	
	Floor to Floor Height		13 ft	13.99 ft	13.99 ft	
1	Minimum U-Value	Roof	0.058	0.063(0.063)	0.037/0.057	For same heat capacity with minImum U-value, Adjusted Insulation
		Wall	0.15	0.124(0.128)	0.061/0.067	
		Floor	0.11	0.137	0.105	
2	Thermal mass		Pre-calculated	Custom	Custom	Weighting Factor
3	Window to wall ratio		15%	51.75%	51.75%	From ACP table in 90.1-1989
4	Glass	U-factor	1.22	1.22	0.31/0.29	
		SC	0.7	0.2/0.49	0.32/0.44	SC Method for DOE-2
		SHGC	0.61	0.17(0.42)	0.28/0.38	
5	Internal Loads	Lighting	1.5	1.3	1.27	w/sqft
		Equipment	0.75	As-built	As-built	
		Schedule	90.1-1989 Prototype	As-built	As-built	People, Lighting, &Equipment
6	Fan Control Type		VFD	Inlet	VFD	
7	TOWER	TWR-SET-T	66F	70F	80F	Leaving Water T.
8	Pump	Heat-Pump-Eff.	0.6	0.75	DOE-2 Default	Combined Impeller & Motor Efficiency
		Cool-Pump-Eff.	0.65	0.87	DOE-2 Default	
		Heat-Pump-Head	60ft	60ft	35ft	
		Cool-Pump-Head	75ft	75ft	50ft	
9	Chiller	SIZE	Auto size	Auto (9.517)	5.58 * 2	
		COP	4.6	6.1	6.59	
		EIR	0.2147	0.1613	0.1547	
10	Boiler	SIZE	Auto size	Auto (3.602)	4.2	
		HIR	1.33	1.25	1.19	EIR= 1/Ec (0.8)
11	DHW	EIR	1.1695	1.171	1.39	EIR= 1/Ef (0.855,0.854)

Table 7.3 Comparison of the Standard 90.1-1989 and 2001 Code Baseline Models

Category	Items	90.1-1989 Baseline		90.1-1989 Baseline		Calibrated	Remarks
		89Model 1	89 Model 2	01Model1	01Model2	As-built	
Weighting Factor		Precalculated		Custom Weighting Factor			
Window-to-Wall Ratio (%)		15	51.75	51.75	51.75	51.75	
Internal Loads	Lighting	1.5	1.5	1.3	1.3	1.27	W/sqft
	Equipment	0.75	0.75	0.74	0.74	0.74	W/sqft
Schedules	Occupancy	As-built Schedules					
	Lighting	As-built Schedules					Measured
	Equipment	As-built Schedules					Measured
Misc. Equip.	Computer Room	52	52	52	52	52	kW
	Senate Print Shop	3.86	3.86	3.86	3.86	3.86	W/sqft
	DP Print Shop	4.56	4.56	4.56	4.56	4.56	W/sqft
	Conference	2.04	2.04	2.04	2.04	2.04	W/sqft
System	AHU Type	SZRH	SZRH	DDVAV	SZRH	DDVAV	
	MIN-CFM-RATIO	0.6	0.6	0.6	0.6	0.6	For VAV
	MIN-OA-RATIO	0.1	0.1	0.1	0.1	0.1	
	DUCT-AIR-LOSS	0.3	0.3	0.3	0.3	0.3	Exhaust Air
	FAN Schedule	1	1	1	1	1	Always On
Temperature Setpoint	COOL-TEMP-SCH	71	71	71	71	71	No setback
	HEAT-TEMP-SCH	71	71	71	71	71	No setback
Exterior Light (Parking +Outside)		72.818	72.818	72.818	72.818	72.818	kW

Table 7.4 Comparison of the Annual Energy Use from Each Simulation Model

Category \ Model	Standard 90.1-1989		Standard 01-2001		REJ Building
	89Model 1	89Model 2	01Model 1	01Model 2	2001 As-built
AREA LIGHTS	9782.5	9782.5	7466.9	7466.9	7294.4
MISC EQUIPMT	8259	8259	8458.8	8458.8	8458.8
SPACE HEAT	15944.4	29276.2	8619.8	5471.3	8646.1
SPACE COOL	9911.4	13631.3	6055.9	5377.5	6497.7
HEAT REJECT	2404.8	3422.3	1219.3	1238	368.2
PUMPS & MISC	647	967	772.8	777.1	789
VENT FANS	7839	10867.3	7340.5	7702	6548.4
DOMHOT WATER	138.8	138.8	135.1	135.1	61.7
EXT LIGHTS	2177	2177.0	2177.0	2177.0	2177
Total (MMBtu)	57103.9	78521.4	42246.1	38803.7	40841.3
Total (kBtu/sqft-yr)	161.5	222.1	136.6	126.0	126.0

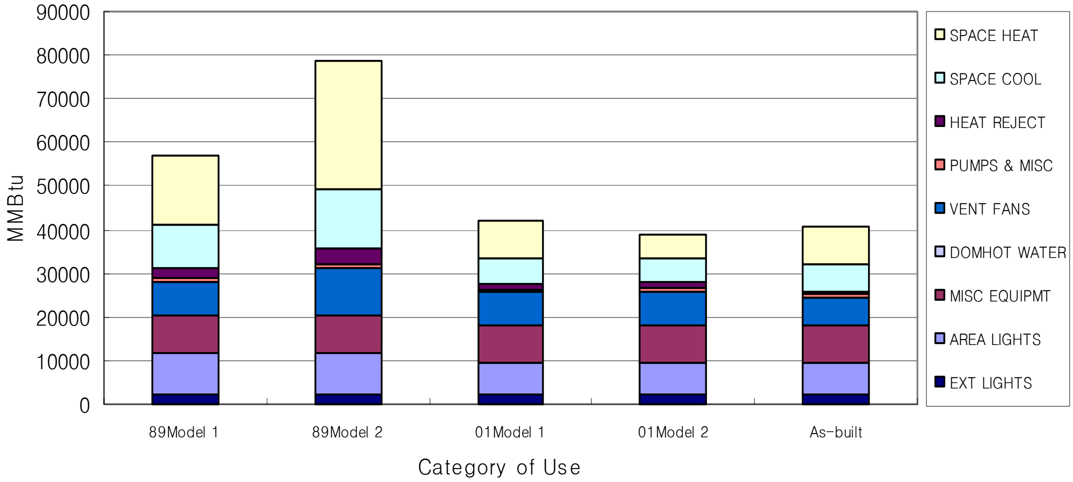


Figure 7.6 *Comparison of the annual energy use (BEPS) for each code model .*

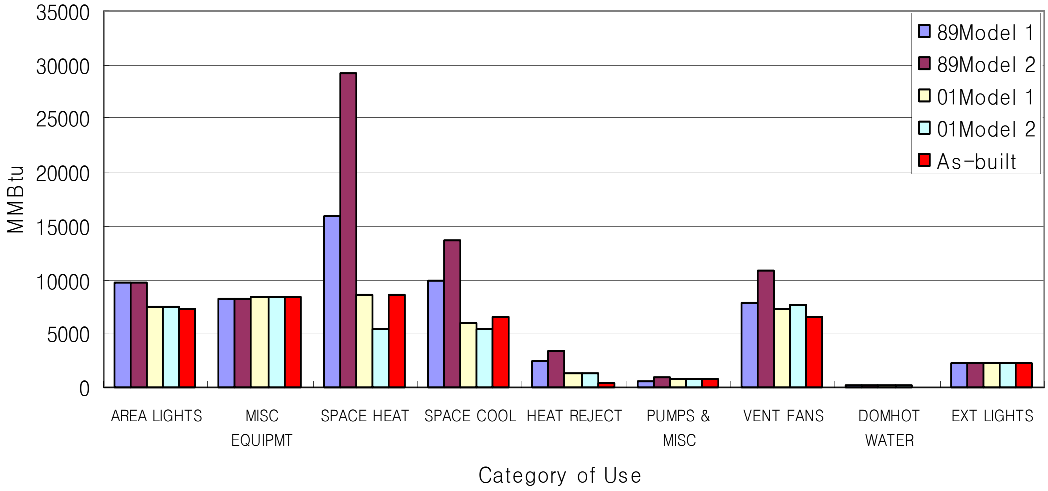


Figure 7.7 *Comparison of annual energy end-use for each code model.*

7.2 Savings Compared to the Standard 90.1-1989 and 2001 Code Baselines

Table 7.5 shows the simulation results from the Standard 90.1-1989 and 2001 code baselines. Energy efficiency was evaluated from the difference between the 90.1-1989 and 2001 code baseline and 2001 calibrated as-built simulation results. Using these results, it was determined that the REJ building is more efficient than the Standard 90.1-1989 and is compliant with Standard 90.1-2001. The REJ building was 20.79% and 2.17% more efficient than the Standard 90.1-1989 and 2001 models, respectively. These results are very different from the design prediction of a 44% reduction compared to the Standard 90.1-1989 in the Eley report (Eley and Tathagat, 1989). The difference between design prediction (44%) and actual savings (20.79 %) is mainly due to differences in building operation and schedule. The prototype building in the Eley report was made using standard schedules of operation and equipment loads from Standard 90.1-1989, while the Standard 90.1-1989 code baseline used in this study was made using as-built building schedules and systems controls as described in Section 7.1.2.

Table 7.5 Simulation Results from the Standard 90.1-1989 and 2001 Code Baselines

Model / Category	Standard 90.1-1989	Standard 90.1-2001	2001 As-built	Energy Savings	
				89 Model	01 Model
AREA LIGHTS	9782.5	7466.9	7294.4	2488.10	172.5
MISC EQUIPMT	8259	8458.8	8458.8	-199.80	0.0
SPACE HEAT	15944.4	8619.8	8646.1	7298.30	-26.3
SPACE COOL	9911.4	6055.9	6497.7	3413.70	-441.8
HEAT REJECT	2404.8	1219.3	368.2	2036.60	851.1
PUMPS & MISC	647	772.8	789	-142.00	-16.2
VENT FANS	7839	7340.5	6548.4	1290.60	792.1
DOMHOT WATER	138.8	135.1	61.7	77.10	73.4
EXT LIGHTS	2177	2177	2177	0.00	0.0
Total (MMBtu)	57103.9	42246.1	40841.3	16262.60	1404.8
Total (kBtu/sqft-yr)	161.5	136.6	132.6	28.90 (20.79 %)	4.0 (2.17 %)

Figure 7.8 shows the Standard 90.1-1989 and 2001 annual energy use compared to the results from the 2001 calibrated as-built simulation. Figure 7.9 compares the end-use energy simulated from each model, including: the Standard 90.1-1989, Standard 90.1-2001, and 2001 calibrated as-built models. In Figure 7.8 and Figure *7.9*, the 2001 heating energy was much less than the 1989 model due to a more efficient boiler as shown in Table 7.2 (i.e., Heat Input Ratio (HIR) is 1.25, Eff.= 80%). The 2001 cooling energy, area lighting, and heat rejection were also less than the 1989 model due to the improved 2001 code requirements as described in Section 7.1.2 .

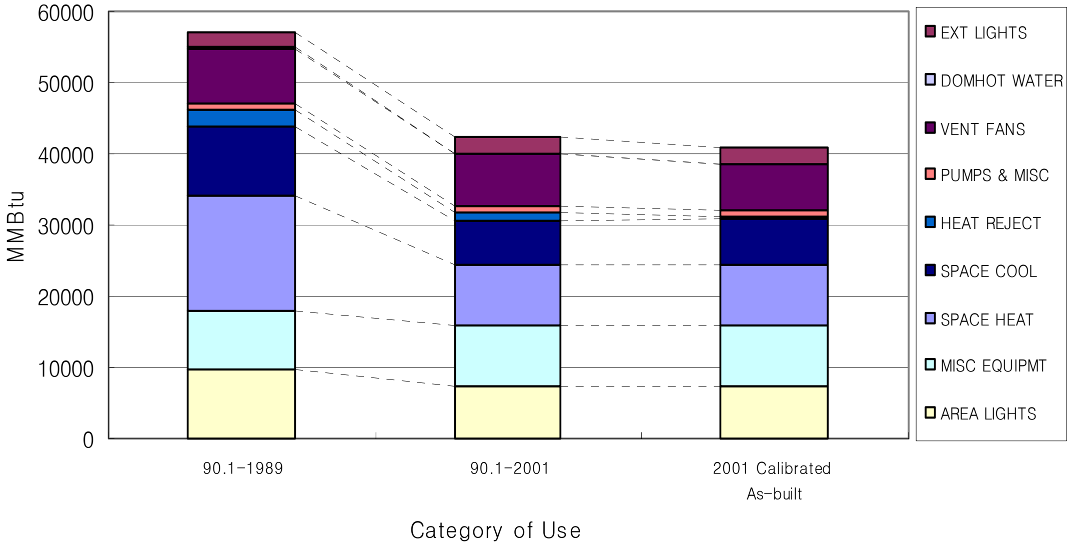


Figure 7.8 *Comparison of annual energy use between Standard 90.1-1989 and 2001 baselines.*

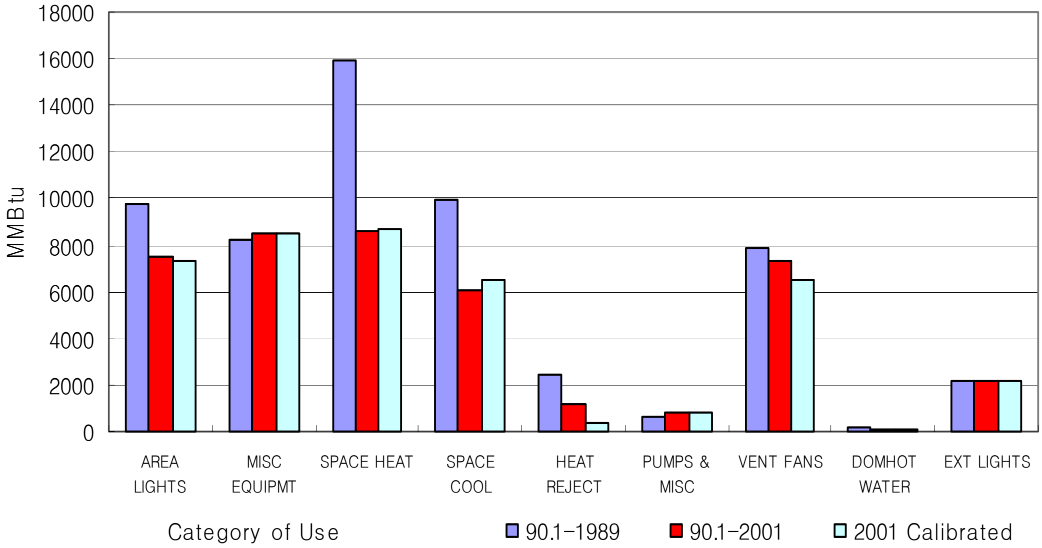


Figure 7.9 *Comparison of annual energy use between the Standard 90.1-1989 and 2001 baselines.*

7.3 Savings from the Energy Conservation Design Measures (ECDMs)

Savings from the Energy Conservation Design Measures (ECDMs) were analyzed with the calibrated 2001 as-built simulation compared to the base-case simulation, which has the same shape and function as the REJ Building, but doesn't include the ECDMs. Table 7.6 shows the ECDMs studied for as-built and base-case simulations used in this study. For the base-case model, efficiencies for plant components were selected from the minimum requirements in the Standard 90.1-1989. Dual-duct constant-air volume (DDCAV) with inlet vane fan and single bronze glazing were also used for the base-case building.

Table 7.6 ECDMs studied for As-built and Base-case Simulations

Items	No	ECDMs	As-built	Base-case	Remarks
Plant	1	High efficient boiler	1.19	1.33	HIR
	2	High efficiency chillers	0.1547 (6.59)	0.2147 (4.6)	HIR (COP)
	3	Over-sized cooling tower	12	9.696(Auto-sized)	MMBtu
	4	Cooling Pump	50	75	Head (ft)
		Heating Pump	35	60	Head (ft)
Systems	5	Air foil type fans	VFD	Inlet	Fan Type
	6	Dual Duct VAV system	DDVAV	DDCAV	AHU type
Building	7	Low-E Window	Low-e	Single Bronze	Glazing Type

In Table 7.7 and Figure 7.10, each standard measure is added separately into the as-built simulation, with the total cumulative values shown as the base case. Table 7.8 and Figure 7.11 represent the energy savings for each ECM in terms of percentage. For example, the efficient boiler (i.e., HIR=1.19, Eff. =84%) are included in the as-built analysis. When they were replaced with standard boilers (i.e., HIR=1.33, Eff.= 75%), the heating energy went from 8,595.7 MMBtu to 9,565.2 MMBtu, which is an increase of 11.3 % for heating and a total increase of 969.5 MMBtu/yr (2.4%). For the efficient chillers (i.e., COP 6.59), when they were replaced with standard chillers (i.e., COP 4.6), the cooling energy went from 6,659.7 MMBtu to 8,918.5 MMBtu, which is an increase of 33.9% for cooling and a total increase of 2,261.5 MMBtu/yr (5.4%). For the over-sized cooling towers (i.e., 12 MMBtu), when they were replaced with the auto-sized towers (i.e., 9.696 MMBtu) by DOE-2, cooling energy was increased by 17.6 MMBtu

(0.2%), but heat rejection energy was decreased by 6.1 MMBtu (1.6%). For the low head pumps, when they were replaced with standard head pumps, pumps and miscellaneous energy was increased by 368.4 MMBtu (46.2%), and a total increase of 394.2 MMBtu/yr (1.0%). For the VFD fan, when they were replaced with inlet vane fans, fan energy was increased by 1,300.1 MMBtu (19.4%), and a total increase of 1,038.4 MMBtu/yr (2.5%). For the DDVAV systems, when they were replaced with DDCAV systems, fan energy was significantly increased by 5,657.9 MMBtu (70.8%), and a total increase of 14,017.1 MMBtu/yr (33.2%). For the low-e windows, when they were replaced with single bronze windows, heating energy was significantly increased by 8,915.4 MMBtu (58.1%), and a total increase of 12,579.9 MMBtu/yr (22.8%). Finally, when all the ECDMs in the as-built model were replaced with the standard components for base-case building, total energy was increased significantly by 36,086.5 MMBtu (67.1%) compared to the as-built simulation. As a result, the as-built REJ building used approximately 67% less energy than the base-case building (i.e., without the ECDMs). Among the ECDMs, low-e glazing and DDVAV systems had the greatest impact on the energy savings as shown in Table 7.8. High efficient chillers, boilers, and fans were also identified as major factors reducing the energy use consumed in the REJ building. As shown in Figure 7.11, heating energy savings were mostly from window and AHU rather than the high efficiency, low-NOx boiler. As expected, the cooling energy was reduced from the chiller. In addition, the window and AHU were also significant factors affecting cooling energy use. Fan electricity use savings were simulated by 19.4% and 70.8% from VFD and DDVAV systems, respectively.

Table 7.7 End-Use Energy Comparison for Each ECDM

Model / Category	As-built	Energy Conservation Design Measures (ECDMs)							Base - case
		Boiler	Chiller	Tower	Pump	Fan	AHU	Window	
AREA LIGHTS	7294.4	7294.4	7294.4	7294.4	7294.4	7294.4	7294.4	7294.4	7294.4
MISC EQUIPMT	8458.8	8458.8	8458.8	8458.8	8458.8	8458.8	8458.8	8458.8	8458.8
SPACE HEAT	8595.7	9565.2	8595.7	8595.7	8579	8185.8	15332.4	17511.1	29538.5
SPACE COOL	6659.7	6659.7	8918.5	6677.3	6699.7	6797.4	8194.4	8021.4	10140.5
HEAT REJECT	372.5	372.5	375.2	366.4	375	383	457	436.4	379.8
PUMPS & MISC	796.8	796.8	796.8	796.8	1165.2	796.8	800.1	819.5	1310.3
VENT FANS	6694.9	6694.9	6694.9	6694.9	6694.9	7995	12352.8	8911.1	17837
DOMHOT WATER	115.3	115.3	115.3	115.3	115.3	115.3	115.3	115.3	115.3
EXT LIGHTS	2177.0	2177.0	2177.0	2177.0	2177.0	2177.0	2177.0	2177.0	2177.0
Total (MMBtu)	41165.1	42134.6	43426.6	41176.6	41559.3	42203.5	55182.2	53745	77251.6
Total(kBtu/sqft-yr)	133.7	136.8	141.0	133.7	135.0	137.0	179.2	174.5	250.9

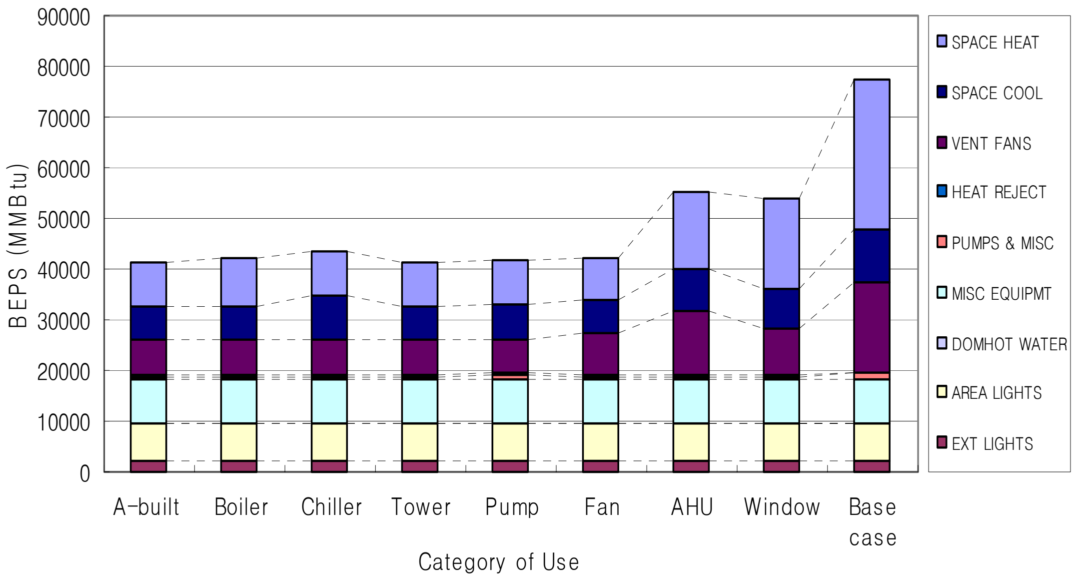


***Figure 7.10** BEPS summary for each ECDMs.*

Table 7.8 End-use Energy Savings (%) from each ECDM

Model / Category	Boiler	Chiller	Tower	Pump	Fan	AHU	Window	Base case
AREA LIGHTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MISC EQUIPMT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SPACE HEAT	11.3	0.0	0.0	-0.2	-4.8	82.3	58.1	119.6
SPACE COOL	0.0	33.9	0.2	0.6	2.1	22.6	16.6	43.4
HEAT REJECT	0.0	0.7	-1.6	0.7	2.8	22.1	14.0	1.7
PUMPS & MISC	0.0	0.0	0.0	46.2	0.0	0.4	2.8	62.7
VENT FANS	0.0	0.0	0.0	0.0	19.4	70.8	17.9	125.0
DOMHOT WATER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EXT LIGHTS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (MMBtu)	2.4	5.4	0.0	1.0	2.5	33.2	22.8	67.1
Total(kBtu/sqft-yr)	2.3	5.3	0.0	1.0	2.4	33.2	22.8	67.2

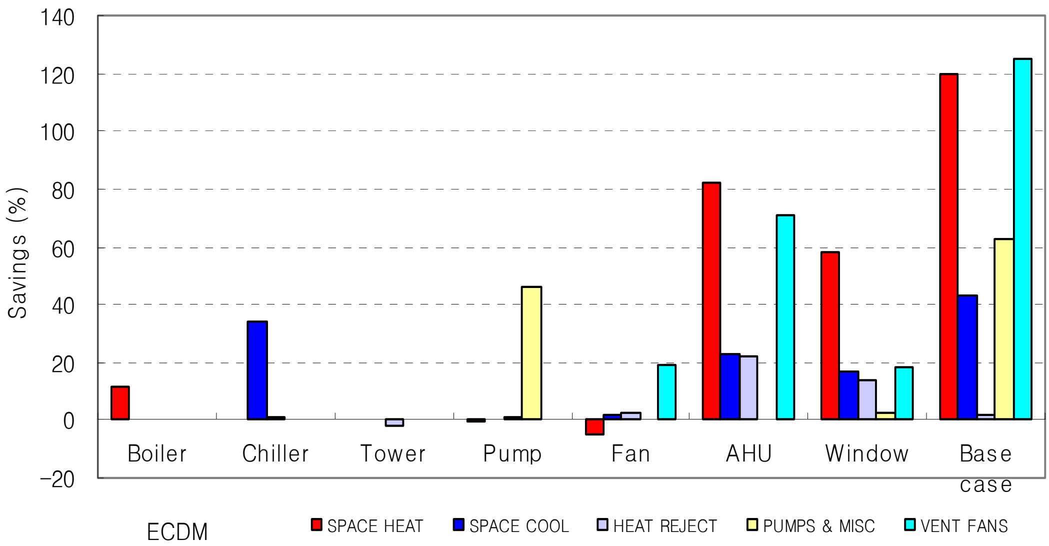


Figure 7.11 *Energy end-use savings percentage for each ECDM.*

7.4 Summary of Energy Performance Evaluation

An Energy Use Index (EUI) comparison, a comparison against ASHRAE Standard 90.1-1989 and 90.1-2001 models, and an evaluation of the performance of specific ECDMs were used to assess the energy performance of the REJ building. The end-use EUIs provided some information about the building's heating and cooling efficiencies, although this remains of limited use in determining the actual performance of the building's systems due to many unknowns in the EUIs. From the comparisons against ASHRAE Standard 90.1-1989 and 90.1-2001 models, It was determined that the REJ building is 20.79 % more efficient than Standard 90.1-1989 and is compliant with Standard 90.1-2001 (i.e., 2.17% less annually). Using an ECDM-subtraction method, the REJ building was shown to use approximately 67% less energy than the base-case building without the ECDMs. Among the ECDMs, low-e glazing and DDVAV systems had the greatest impact on the energy savings. High efficient chillers, boilers, and fans were also identified as significant factors reducing the energy use consumed in the REJ building.

CHAPTER VIII

POTENTIAL SAVINGS FROM IMPROVEMENTS

In the process of the as-built model calibration as described in Chapter 6.4, selected savings opportunities were identified and then applied to the final 2004 calibrated as-built simulation to predict potential energy savings, including: minimum terminal box supply air flow, duct air loss/exhaust, and daylighting.

8.1 Minimum Supply Air Flow and Undocumented Exhaust Air

Table 8.1 and Table B.2 show the DOE-2 parameter and simulation results for two simulated improvements. For the DDVAV system, the minimum air flow was set to 0.3 from 0.6, which was used for the calibration of the as-built simulation. The 30% reduction of minimum supply air flow significantly reduced heating energy use by 2,660.8 MMBtu, and total energy use by 5,537.3 MMBtu (15.14%). A 10% reduction in the duct air loss decreased total energy use by 2,239.3 MMBtu (6.14%). Total energy savings were calculated to be 7,053.3 MMBtu (19.26%) from the combined improvements (improvement 1+2) for the case-study building. Figure 8.1 and Figure 8.1 show the simulation results including energy end-use for each improvement. Most of the savings from improvement 1were identified from space heating, while savings from improvement 2 were identified from space heating, cooling, and fan energy use.

Table 8.1 DOE-2 Parameters for Improvement Simulation

DOE-2 Keywords		Base Model	Improvement 1	Improvement 2	Improvement (1+2)	Remarks
1	MIN-CFM-RATIO	0.6	0.3	0.6	0.3	Min Flow Rate
2	DUCT-AIR-LOSS	0.3	0.3	0.2	0.2	Undocumented Exhaust Air

Table 8.2 Simulation Results from Improved Simulation Models

Model / Category	2004 As-built	Improvement 1	Improvement 2	Improvement (1+2)	Savings: Improvement 1	Savings: Improvement 2	Savings: Improvement (1+2)
AREA LIGHTS	7,219.1	7,219.1	7,219.1	7,219.1	0.0	0.0	0.0
MISC EQUIPMT	8,339.4	8,339.4	8,339.4	8,339.4	0.0	0.0	0.0
SPACE HEAT	4,804.3	2,257.9	4,319.9	1,992.0	2,660.8	598.8	2,926.7
SPACE COOL	6,136.2	5,675.6	5,553.5	5,018.7	632.5	754.6	1,289.4
HEAT REJECT	346.5	322.2	311.8	295.1	29.5	39.9	56.6
PUMPS & MISC	782.3	575.5	560.0	558.4	5.5	21.0	22.6
VENT FANS	6,403.7	4,389.7	5,773.7	3,840.7	2,209	825.0	2,758
DOMHOT WATER	61.7	115.3	115.3	115.3	0.0	0.0	0.0
EXT LIGHTS	2177.0	2177.0	2,177.0	2,177.0	0.0	0.0	0.0
Total (MMBtu)	36,270.2	31,071.7	34,369.7	2,9555.7	5,537.3	2,239.3	7,053.3
Total(kBtu/sqft-yr)	117.8	100.9	111.6	96.0	18.0 (15.14%)	7.3 (6.14%)	22.9 (19.26%)

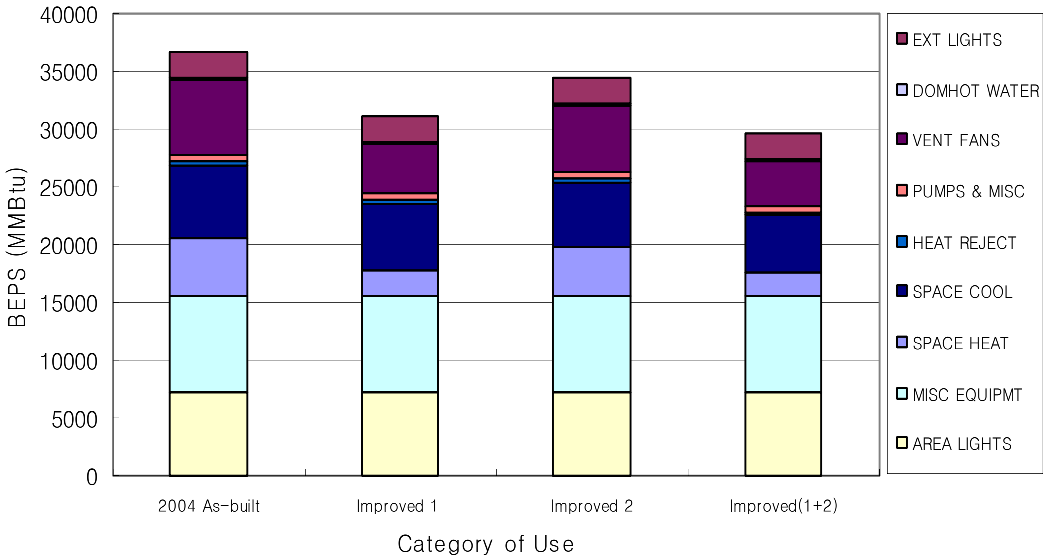


Figure 8.1 *Comparison of total annual energy use for each improvement.*

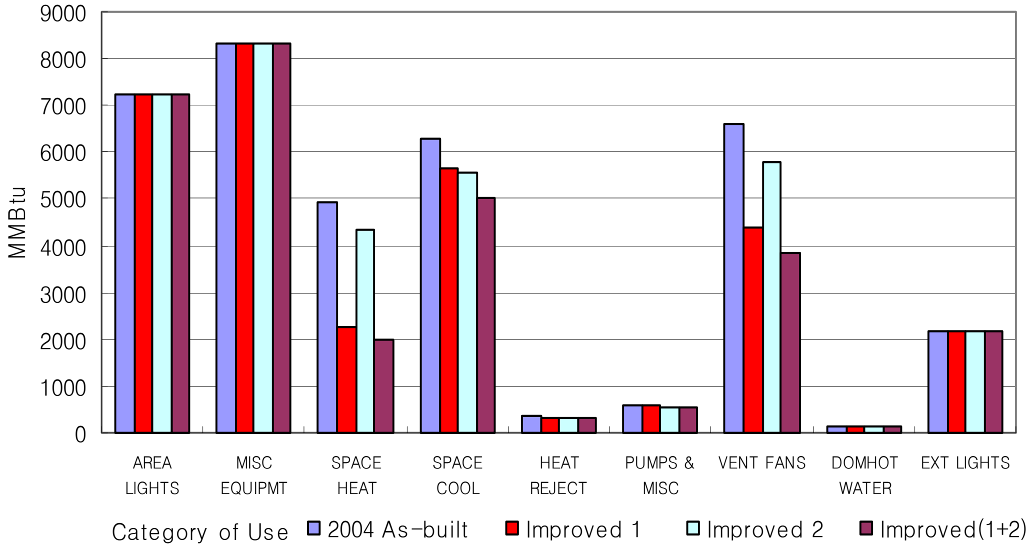


Figure 8.2 *Comparison of annual energy end-use for each improvement.*

8.2 Daylighting

As described in Chapter IV, Section 4.1, specially designed light shelves with dimmable ballasts were installed on a portion of the south façade (3rd through 5th floors) of the building to project the daylight into the interior office. However, on-site inspections (Sylvester et al., 2002) revealed that most window blinds were closed on all glazed surfaces, negating the effect of the daylighting-dimming equipment. In this study, potential savings from the dimming systems were approximately predicted using a proxy method for the perimeter zones on the 2nd and 6th floor as shown in Figure 8.3. Figure 8.4 shows maximum lighting energy savings on vernal equinox, which represent clear sky conditions with high daylight availability, for the selected south zone on 4th floor as colored in gray in Figure 8.3. As a result, the dimming systems reduced lighting electricity use by 35.5% and 33.96% for the 40 and 60 foot-candle (fc) interior lighting level, respectively. Table 8.3 and Figure 8.5 show the end-use energy savings from the daylighting simulation for the perimeter zones from 2nd floor to 6th floor of the REJ building. Whole-building lighting electricity use was reduced by 1,338.6 MMBtu (18.5%), with a total reduction of 2,055.8 MMBtu (5.6%). In Figure 8.5, space cooling and fan energy savings were also identified to be 325.7 MMBtu (5.2%) and 279.5 MMBtu (4.2%) due to daylighting effects.

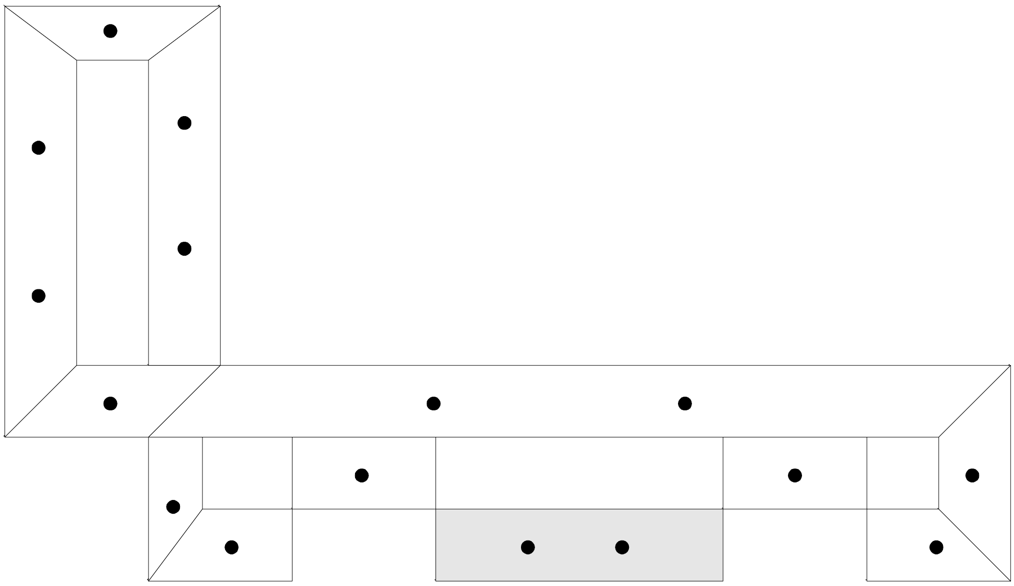


Figure 8.3 *Reference points on typical floor for the DOE-2 daylighting simulation.*

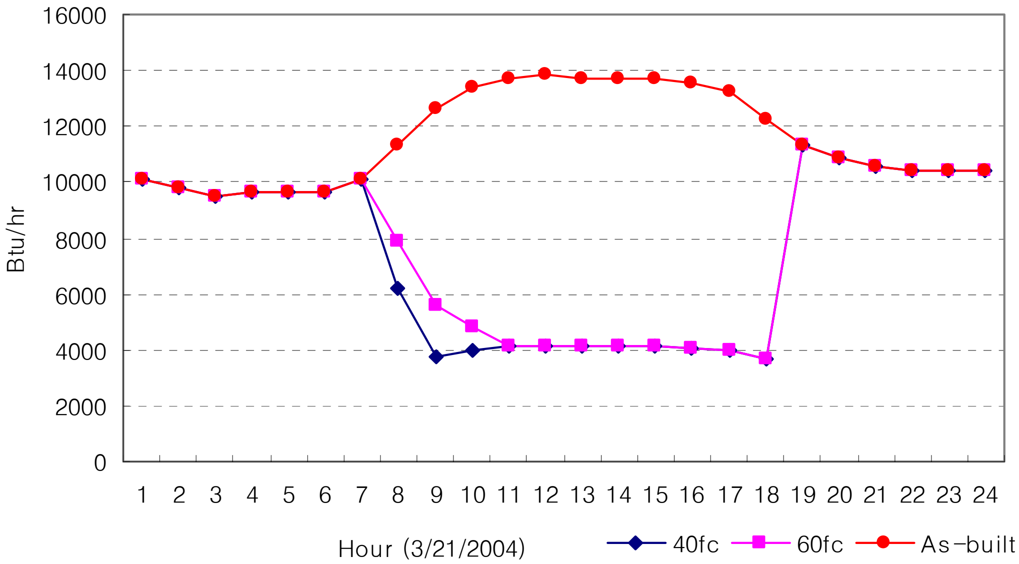


Figure 8.4 *Simulated lighting electricity use with dimming systems on March 21, 2001.*

Table 8.3 End-use Energy Savings from Daylighting

Category \ Model	2004 As-built	Daylight	Savings	
			MMBtu	%
AREA LIGHTS	7219.1	5880.5	1338.6	18.5
MISC EQUIPMT	8339.4	8339.4	0.0	0.0
SPACE HEAT	4918.7	4836.9	81.8	1.7
SPACE COOL	6308.1	5982.4	325.7	5.2
HEAT REJECT	351.7	329.5	22.2	6.3
PUMPS & MISC	581.0	573.0	8.0	1.4
VENT FANS	6598.7	6319.2	279.5	4.2
DOMHOT WATER	115.3	115.3	0.0	0.0
EXT LIGHTS	2177.0	2177.0	0.0	0.0
Total (MMBtu)	36609.0	34553.2	2055.8	5.6
Total(kBtu/sqft-yr)	118.9	112.2	6.7	5.6

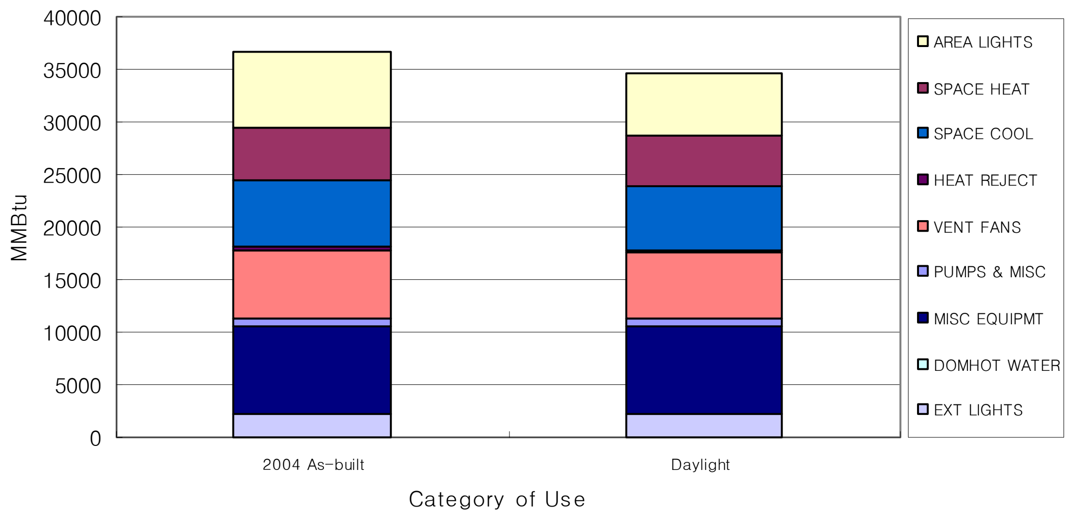


Figure 8.5 *Comparison of annual energy use for daylighting.*

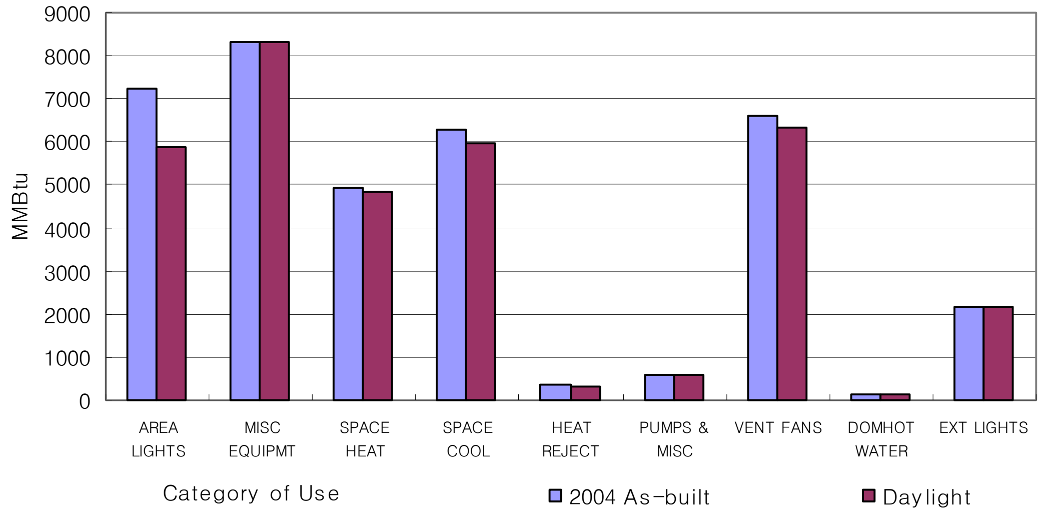


Figure 8.6 *Annual end-use energy savings from daylighting.*

8.3 Summary of Potential Energy Savings

Potential savings from the proposed improvements were simulated to be 7,053.3 MMBtu (19.26%) from the combined improvements (Improvements 1+2) when compared to the 2004 as-built simulation. For the DDVAV system, a 30% reduction of supply air flow reduced total energy use by 5,537.3 MMBtu (15.14%). A 10% reduction in exhaust air decreased total energy use by 2,239.3 MMBtu (6.14%). Lighting electricity use was reduced by 18.5% and total energy reduced by 5.6% when daylighting was simulated in all the perimeter zones from 2nd floor to 6th floor of the REJ building.

CHAPTER IX

SUMMARY AND CONCLUSIONS

9.1 Summary of Study Objectives

In summary, the purpose of this research is to develop and test methodologies for the performance evaluation of new commercial buildings using calibrated simulation. The main objectives of this research are: 1) To develop improved M&V Methods with in-situ measurements for new buildings, 2) To analyze and develop simulation and calibration methods applicable to new commercial buildings, which utilize Energy Conservation Design Measures (ECDMs) (i.e., high performance windows and energy efficient equipment), 3) To develop and compare different energy use baselines, such as a code-compliant baseline with ASHRAE Standard 90.1-1989 (ASHRAE, 1989) vs. Standard 90.1-2001 (ASHRAE, 2001), a design condition without ECDMs, and reference buildings in a control group, and 4) To demonstrate the proposed procedures using a case-study building.

9.2 Summary of the Methodologies

To accomplish the purpose and objectives above, several methods were developed and used in this study, in terms of: 1) Energy Measurement and Verification (M&V), 2) Simulation and calibration methods, and 3) Building energy baselines and Savings assessments.

1. Measurement and Verification (M&V) Methods

Whole-building energy metering and in-situ measurements for selected components, including: low-e glazing, high-efficiency chiller, and dual-duct air handling units, were performed. As a result, several new methods were analyzed and developed in this study as follows:

1) The development of a procedure to synthesize weather-normalized cooling energy use (i.e., Btu cooling production) from a correlation of MCC electricity use,
2) The development of an improved method to analyze measured solar transmittance against incidence angle for sample glazing using different solar sensor types, including: Eppley PSP and Li-Cor sensors, and

3) The development of an improved method to analyze chiller efficiency and operation at part-load condition.

2. Simulation and Calibration Methods

Simulation and calibration methods applicable to new commercial buildings were developed and used, including: measured weather data packed into TRY format, typical load day-typing, building thermal mass, low-e window performance, HVAC system performance, and graphical and statistical evaluation. Four new methods were also analyzed and developed in the process of the as-built model simulation and calibration as follows:

1) The development of new percentile analysis to the previous signature method (Wei et al., 1998) for use with a DOE-2 calibration,
2) The development of a new method to account for undocumented exhaust air,
3) An analysis of the impact of synthesized direct normal solar radiation using the Erbs correlation (Duffie and Beckman, 1991) on DOE-2 simulation, and
4) A verification of the DOE-2's solar transmittance against incidence angle for low-e glazing with window libraries generated using the Window 5.2 program.

3. Building Energy Baselines and Savings Assessment

Three different energy baselines were developed to calculate actual energy savings, including: a code-compliant baseline with ASHRAE Standard 90.1-1989 (ASHRAE, 1989) vs. Standard 90.1-2001 (ASHRAE, 2001), a comparison of design conditions without ECDMs, and a comparison to reference buildings in a control group. The following tasks were performed in this study using the case-study building:

1) A comparison of the code-compliant baselines with two different window-to-wall ratio (15% vs. 51.45%) and AHU systems types (SZRH vs. DDVAV) for the Standard 90.1-1989 and 2001,
2) An analysis of the actual energy savings compared to different baselines for the case-study building, including whole-building and component energy performance,

3) An analysis of the energy savings potential from selected improvements, including: minimum supply air flow, undocumented air loss, and daylighting.

9.3 Summary of the Results

9.3.1 Summary of the Measured Data from the Case-Study Building

Measured data from the case-study building were analyzed to verify the as-built building energy performance and operations for the years 2001 and 2004, including: 1) utility billing data, whole-building energy use, and component performance, such as chiller efficiency, typical AHU operation, and measured solar transmittance of the new low-e glazing. From the monthly utility billing analysis, it was observed that the case-study building began to normally operate in 2001. Measured data were also verified with monthly utility data for 2001 and 2004. Measured data from the whole-building energy metering were analyzed, including: whole-building electricity use, motor control center (MCC) electricity use, lighting and receptacles (WBE-MCC) electricity use, cooling energy use, and heating energy use.

In 2003, a new chiller was added to the case-study building, which was not separately metered. Therefore, the 2004 cooling energy use was synthesized based on a correlation with MCC electricity use including total chiller electricity use. The measured chiller efficiency was first compared to the manufacturer's data and then analyzed according to the parallel and sequence chiller operation mode. To accomplish this, the measured chiller efficiency at full loads was incorporated into the as-built DOE-2 simulation for the case-study building. For part-load conditions, the DOE-2 default curve was used since the measured data curves were found to be very similar to the DOE-2 default curves.

Several temperature and RH points were measured to verify the actual operation and condition for a typical air handling unit (AHU) located on the 4^{th} floor of the case-study building, using portable data loggers, including: hot deck, cold deck, and supply and return air temperatures. The hot deck and cold deck temperatures were grouped according to the operation periods. The measured data were than incorporated into the DOE-2 simulation to calibrate the as-built simulation model.

A three-way comparison of the measured solar transmittance against incidence angle was performed using Eppley PSPs, Li-Cor solar sensors, and the Window 5.2 program. The three-way comparison showed that the solar transmittance measured by Li-Cor provided an accurate match to the

Window 5 data for incidence angle less than 50 ^{o}. The data from the PSP overstates the solar transmittance because the thermopile-type sensor used in the PSP is biased by the heat from the sample glazing.

9.3.2 Summary of As-built Simulation and Calibration

Three different as-built simulation models were developed in this study. A 2001 as-built model was first developed based on as-built design conditions. This was then calibrated with 2001 measured data for evaluating the 2001 energy performance compared to the 2001 energy baselines. A 2004 calibrated as-built model was also developed to evaluate the potential energy savings from the proposed improvements. Then, the 2004 model was used to develop a detailed simulation and calibration based on the methods with significant calibration factors applicable to new buildings, including: weather data packed into TRY format, typical load day-type profiles, custom weighting factors (CWFs) with U-effective calculation for underground surfaces, low-e window library using Window 5.2, HVAC systems performance curves, and enhanced signature methods with percentile analysis. As a result, the final calibrated model was determined to have overall 20.38% CV(RMSE) and a 0.63% MBE for the 2001 model and 23.82% CV(RMSE) and a 0.61% MBE for the 2004 model. The calibration results compares well with previous research for new buildings, which had a 23.1% CV(RMSE) and a -0.7% MBE by Bou-Saada (1994). According to the ASHRAE Guideline 14-2002 (2002) pp.41, "Models are declared to be calibrated if they produce NMBE with ±10% and CV(RMSE) within ±30% when using hourly data, or 5% or 15% with monthly data."

9.3.3 Summary of the Energy Performance Evaluation

Energy performance evaluations were developed, including: an Energy Use Index (EUI) comparison, a comparison against ASHRAE Standard 90.1-1989 and 90.1-2001 models, and an evaluation of the performance of specific ECDMs. It was determined that the end-use EUIs provided some information about the building's heating and cooling efficiencies. However, this remains of limited use in determining the actual performance of the building's systems. From the comparisons against ASHRAE Standard 90.1-1989 and 90.1-2001 models, it was determined that the REJ building is 20.79% more efficient than the Standard 90.1-1989 and approximately equal to the Standard 90.1-2001. In the process of developing the as-built model calibration, selected savings factors were identified and then applied to the

2004 calibrated as-built simulation to predict potential energy savings, including: minimum supply air flow, duct air loss, and daylighting. Potential savings from the proposed improvements were measured to be 7,053.3 MMBtu (19.26%) from the combined improvements when compared to the 2004 as-built simulation. For the DDVAV system, a 30% reduction of minimum supply air flow reduced total energy use by 5,537.3 MMBtu (15.14%), and a 10% reduction of duct air loss decreased total energy use by 2,239.3 MMBtu (6.14%). Lighting electricity use was reduced by 18.5% and total energy was reduced by 5.6% when daylighting controls were applied to the perimeter zones from 2nd floor to 6th floor of the REJ building. Table 9.1 shows the overall simulation results from the different energy baselines and as-built simulation models. Figure 9.1 compares the annual total energy use for each model developed in this study.

Table 9.1 Simulation Results from the Energy Baselines and As-built Simulation Models

Model Category	Standard 90.1-1989	Standard 90.1-2001	2001 As-built	2004 As-built	2004 Improved	Savings		
						89 Model	01 Model	Improved
AREA LIGHTS	9782.5	7466.9	7294.4	7219.1	7219.1	2488.10	172.5	0
MISC EQUIPMT	8259	8458.8	8458.8	8339.4	8339.4	-199.80	0.0	0
SPACE HEAT	15944.4	8619.8	8595.7	4918.7	1992	7348.70	24.1	2926.7
SPACE COOL	9911.4	6055.9	6659.7	6308.1	5018.7	3251.70	-603.8	1289.4
HEAT REJECT	2404.8	1219.3	372.5	351.7	295.1	2032.30	846.8	56.6
PUMPS & MISC	647	772.8	796.8	581	558.4	-149.80	-24.0	22.6
VENT FANS	7839	7340.5	6694.9	6598.7	3840.7	1144.10	645.6	2758
DOMHOT WATER	138.8	135.1	115.3	115.3	115.3	23.50	19.8	0
EXT LIGHTS	2177	2177	2177	2177	2177	0.00	0.0	0
Total (MMBtu)	57103.9	42246.1	41165.1	36609	29555.7	15938.80	1081.0	7053.3
Total(kBtu/sqft-yr)	161.5	136.6	133.7	118.9	96.0	27.80 (20.79%)	2.9 (2.17%)	22.9 (19.26%)

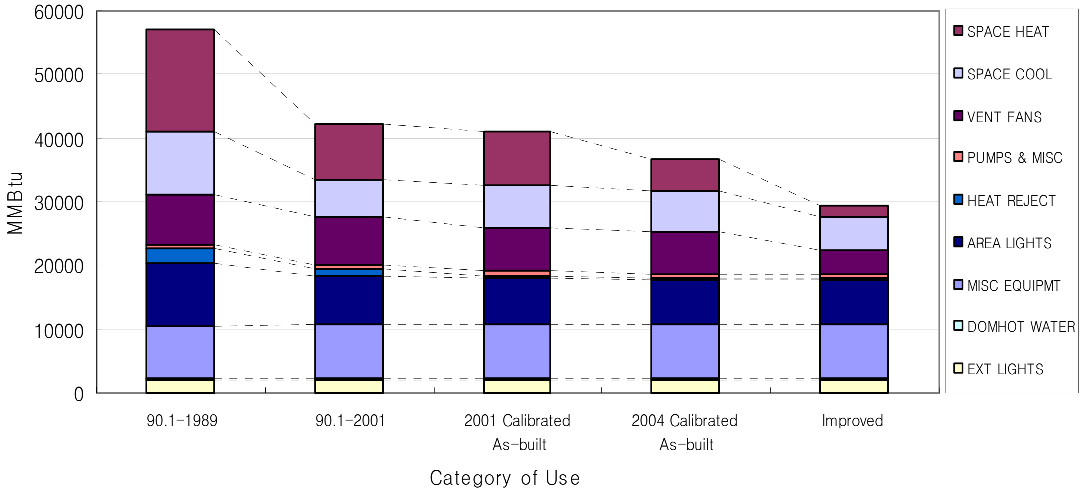


Figure 9.1 *Comparison of annual total energy use.*

9.4 Recommendations for Future Research

This research was limited to evaluations of whole-building energy performance for a case-study building, with a selected ECDMs that were simulated using the DOE-2.1e program, including: a high efficiency boiler, chiller, an oversized cooling tower, low head pumps, VFD fans, Dual-duct VAV systems, and low-e glazing. Unfortunately, some of the ECDMs installed in the REJ building could not be simulated in this study due to limitations with the DOE-2.1e program and sub-metered data, including: enthalpy-based heat recovery on the senate print shop, dual-duct dual fan AHUs, and a run-around glycol coil. These measures require a more sophisticated simulation program and sub-metered data for the certain component. The following topics are recommended for future research:

9.4.1 REJ Building:

This study has also identified the following potential savings measures at the REJ building:

1) A need for commissioning to improvements, including: appropriate set points, chiller operation, outside air control, and exhaust air control,
2) A need for integrated daylighting with office furniture, and

3) A need for verification of ECDMs not covered in this study, including: enthalpy-based heat recovery, dual-duct dual fan AHU, and a run-around glycol coil.

4) A need for developing a method of switching chiller performance curves in either sequence or parallel mode at part-load conditions

9.4.2 Process in General

Finally, this study has identified the following improvements to the process of calibrating a simulation program.

1) A need for simulation programs with actual component models based on first principals vs. curve-fits such as those in DOE-2,
2) A need for protocols for practitioners to use to cost-effectively measure performance, and
3) A need to integrate design model to run side-by-side with ECDMs.

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APPENDIX A

SUMMARY OF THE ENERGY PERFORMANCE EVALUATION OF SIX HIGH PERFORMANCE BUILDINGS BY NREL

For the whole-building energy evaluation, a set of performance metrics were developed for each site. Detailed performance evaluation methods used by NREL are described as follows in terms of monitoring, benchmark model, as-built simulation, and savings calculations. Table A1 summarizes the energy performance evaluation methods and savings of the six high performance buildings performed by NREL.

A1. Oberlin

The Adam Joseph Lewis Center for Environmental Studies in Oberlin, Ohio, in a heating-dominated climate is a two-story, 13,600 sq-ft classroom and laboratory building, which was designed to a be net zero energy building with a roof-integrated photovoltaic (PV) systems and other energy-efficient features, including: daylighting, natural ventilation, massive building materials, a ground-source heat pump system, wastewater treatment, and an energy management system.

1.1 Monitoring

After the building was constructed, NREL performed long-term measurements (2001-2003) to evaluate its whole-building energy performance. They installed a permanent data acquisition system (DAS), which consists of two Campbell Scientific data loggers with network interface and all the necessary sensors, including: whole-building electricity use, PV production, HVAC, lighting, and miscellaneous equipment electricity use. The expected accuracy of the sensors used in the monitoring system was determined from product specification. Individual electricity measurements were 0.5% based on the manufacturer's data. Every few minute's data were stored on the server. Hourly data were then transferred into an analysis and error checking spreadsheet program each day. The spreadsheet program calculated an energy balance and presented summary data for easy inspection.

1.2 Benchmark (Base-case model)

Base-case model was developed as specified in Addendum E of ASHRAE 90.1-2001, using the DOE-2.1E simulation program with TMY2 weather data from Cleveland, Ohio. The base-case building is a solar-neutral, two-story square model of equal size and space use. The model includes the same amount of glass (43% of window-to-wall ratio) as the as-built building, but doesn't take advantage of daylighting and has no overhangs. Minimum thermal characteristics such as R-value were used to define the envelope in the base-case model. Maximum lighting power densities specified in the code were defined in each space condition, but equipment power density was modeled based on installed equipment in each space. Occupancy schedules were based on the calibrated as-built schedule, and equipment and lighting schedules were based on the occupancy schedules. The heating and cooling equipment and efficiencies were based on typical electrical HVAC equipment specified by ASHRAE 90.1-2001.

1.3 As-built simulation

As-built models for the second year (March 01–February 02) and third year (March 02–February 03) of operation were created using the DOE-2.1 program, basically based on as-built conditions with separated thermal zone according to space use, location, and floor. To calibrate the model, assumptions such as heating and cooling schedules, occupancy schedules, and unoccupied infiltration were slightly tuned until the simulation results matched with measured data. The HVAC system was modeled using the manufacturer's rated performance data and some simplifying assumptions. The TMY2 weather file was created based on measured meteorological site conditions and global solar radiation for the as-built simulation. They compared HDD and CDD between measured and TMY2 weather data. However, they didn't describe how to pack the TMY2 weather file including solar radiation.

1.4 Sub-systems analysis

For the performance analysis of sub-systems, additional measurements and individual simulation were conducted. The wastewater treatment process loads (water pumps, water treatment equipment, and exhaust fans) were independently monitored, which accounted for 10% of the total energy use. It was determined that HAVC was responsible for 59% of the total energy use. For the PV system analysis, the PV system simulation tool, PVSyst v3.2 (Mermoud 1996), was used to calculate the expected annual performance and the Sandia photovoltaic performance I-V Curve tracer (King et al. 1998) was also used to evaluate the effects of operating voltage on PV production. The diffuse radiation component in the plane of the collector was calculated using an isotropic index method by Hay and Davis (Hay and Davis, 1978). IEA/SHC Task 21 monitoring method was adapted to measure indoor illuminance level. A savings of 34% was estimated due to lighting design and 76% savings due to occupancy sensors and daylighting when compared to the base-case simulation. Ground source heat pump was evaluated to determine the reduction in capacity and COP due to the ARI-320 rated heat pumps operating at typical ground source entering water temperatures (EWT).

1.5 Summary

Performance of the Oberlin was measured in the following ways: Energy performance evaluation was conducted after occupancy. The evaluation focused on the whole-building performance rather then individual building components. The evaluation period was 2001 through February 2003. For the first year, NREL used utility bills to evaluate energy performance and then developed a monitoring plan. Performance evaluations were performed for two more years (March 1, 2001 until February 28, 2003). Based on the performance of the third year, the site energy savings were 48% from the comparison of the simulation results between the base-case (benchmark model) and as-built model with TMY2 weather data. Energy cost savings (35%) were also evaluated as compared to utility bills against the results from as-built simulation with measured site weather data (TMY2). Furthermore, NREL developed a list of improvements in terms of equipment and operational issues. It was predicted, using an optimized model, that the site energy savings could be increased to 64%, with 85% of the building load met by the PV system.

B2. Zion Visitor Center

The Visitor Center Complex at Zion National Park in Utah consists of two buildings: an 8,800 sq-ft main visitor center and a 2,756 sq-ft restroom facility. The building was constructed with respect to minimizing energy and environmental impact, along with energy-efficient features including: daylighting, natural ventilation, cool towers.

2.1 Monitoring

Energy use measurements were taken at the main utility meter and PV system connections. The building's BAS measured and recorded energy flows every 15 minutes from September 2000 through June 2003. End uses are grouped into HVAC, lighting, and equipment loads, and have each end use meters. Site weather variables were also monitored, including: outdoor dry-bulb temperature, relative humidity, wind speed and direction, and horizontal and vertical irradiance. The expected accuracy of the sensors was ranged from 0.36% (temperature) to 3% (humidity) based on manufacturer's literature. The energy consumption from the main utility meter was compared to the sum of all the other end-use meters, which yield a 1.4% error, with a linear correction of nearly one. The utility meters are related to 0.5 % accuracy of full-scale and total error possible of the data is 1.51 %, which was considered reliable.

2.2 Benchmark

The base-case model was initially developed using the DOE-2.1E simulation program, based on the proposed design and remodeled later with as-built characteristics. The initial base case was modeled as a square, solar neutral (equal glazing areas on all orientations) and met the minimum requirements of the Federal Energy Code 10 CFR 435 (DOE, 1995), which is based on ASHRAE Standard 90.1-1989 (ASHRAE, 1989) with additional lighting requirements. Occupancy schedules were based on typical operation hours of the existing facility. Outside ventilation air was set to constant rate during occupied hours, equal to 15 cfm per person. Depending on the zone, lighting levels were set to retail, office, and exhibit lighting levels with no reduction for daylighting. Minimum R-values were set for envelope in the base-case model. The heating and cooling equipment represent typical electrical HVAC equipment compliant with the federal energy code. Many of the base-case characteristics were based on typical park practice information provided by NPS staff. After occupancy, the case-case model was calibrated with measured weather data and measured equipment loads, and operational condition. In fact, comfort station was added to the initial model and actual heating and the cooling set point was set to the new base-case model. Lighting power densities were remodeled in each zone.

2.3 As-built simulation

The as-built simulation model was not developed due to limitations in the whole-building simulation tools, such as difficulties modeling the as-built operation of demand controls with integrated PV production and uncertainties with Trombe wall thermal models.

2.4 Sub-systems analysis

NREL evaluated the sub-systems, including: the HVAC system, lighting, daylighting, and PV system. It was estimated that the majority of HAVC energy use was for heating panel. For the PV system analysis, the PV system simulation tool, PVSyst v3.2 (Mermoud, 1996), was used to calculate the expected annual performance and the Sandia photovoltaic performance I-V Curve tracer (King et al., 1998) was also used to evaluate the effects of operating voltage on PV production. The IEA/SHC Task 21 monitoring method was adapted to measure indoor illuminance levels. A savings of 50% was estimated due to the lighting design and 50% due to occupancy sensors and daylighting, when compared to the base-case simulation. Twelve temperature sensors were installed on the walls and three on the ceiling. As a result, several histograms of hours at average temperature were developed to evaluate thermal comfort.

2.5 Summary

Performance of the Zion Visitor Center was measured in the following ways. Energy savings were first predicted with a proposed design model at the end of the design stage. The energy cost savings were approximately 80% as compared to the benchmark (base-case) model. The base-case model was remodeled with as-built characteristics to provide a better comparison for evaluating energy savings. It was estimated that the energy cost was 67% less energy than the updated base-case model when directly compared to utility bills from November 2001 through October 2002. The reason the energy cost savings are less then the expected 80% savings is due to the difference between as-built building and the proposed design, in terms of daylighting systems design (e.g., clear story and ceiling colors) and heating systems types. The post occupancy evaluation measured energy performance, including: measuring building end-uses, evaluating lighting and daylighting systems, evaluating PV systems, and assessing occupant comfort.

3. TTF

The Thermal Test Facility (TTF) was constructed in 1996 for a research laboratory and an office building at the NREL in Golden, Colorado. The TTF building also incorporates many passive solar and energy-efficient features that minimize building electrical loads, while maintaining occupant comfort.

3.1 Monitoring

For the whole-building monitoring, the energy management system (EMS) was used to collect and store data. The data were collected twice each day as the storage capacity of the EMS was limited. Additional points were added for the measurement points that were not controlled under the EMS system. A separate program on the PC was written to periodically compile the files into single monthly text files with all recorded information from April 1997 through December 1999. Some data were lost because the system was not stable enough to maintain long-term reliability. The expected accuracy of the sensors ranged from 0.36% (temperature) to 3% (humidity) based on manufacturer's literature. Short-term tests were also used to verify some parameters. These tests included blower door, trace gas, and short-term energy monitoring (STEM). Calibration was done only when the desiccant and battery experiment were not running.

3.2 Benchmark

The base-case model was developed using the DOE-2.1E simulation program in the design stage, based on typical code-compliant buildings that met the minimum requirements of the Federal Energy Code 10 CFR 435 (DOE 1995). The base-case model has the same size as the TTF building. However, several assumptions were also made, such as an equal footprint and wall area and total window-to-wall ratio of 13.3 % applied on all sides for a solar-neutral building. Plug loads, set-point schedules, and occupant loads would be identical between the buildings. TMY2 weather data for Denver, Colorado, were used for the base-case simulation. VAV mechanical systems are typical for buildings of this type and size in the Denver area. Supply fans were controlled to cycle on and off for heating, cooling, or outdoor air requirement. It seems that they also didn't account for building thermal mass effect and HVAC equipment capacity that should be auto-sized from the simulation load of the base-case model. The base-case model was modified later to reflect the same set point and schedules as the as-built model to calculate energy savings.

3.3 As-built simulation

As-built models were created using the DOE-2.1 program, basically based on as-built conditions with measured weather data, measured infiltration, and short-term energy monitoring (STEM). Measured weather data were packed to TMY2 format, including: measured direct normal and horizontal solar radiation. Infiltration rates were determined by a tracer-gas analysis, which resulted in an infiltration rate of 0.1 ACH during unoccupied periods. During occupied hours, it is assumed that no infiltration occurs because positive building pressure results from operation of the HVAC system. STEM analysis produces information needed to accurately extrapolate annual building performance results from collected data over a short time. Lighting level set points in the model were adjusted to match actual lighting performance of the building, but modeled lighting loads tend to be slightly higher than actual measured data. Based on measured data and the as-built drawings, zone set points, HVAC equipment, schedules, and power loads were also adjusted for the calibration of the as-built simulation model. NREL considers a building simulation to be calibrated when the simulated monthly energy use is within 12% of the measured data.

3.4 Sub-systems analysis

Daylighting and thermal comfort were analyzed for the performance evaluation of sub-systems. Qualitative and quantitative assessments of the TTF's daylighting performance were performed. Photographs taken with daylight were used to capture the qualitative impact of the daylighting in the space. Quantitative measurements were performed to better understand lighting based on the protocols developed as part of the IEA/SHC-Task 21/Annex 29, Subtask (Atif et al. 1997). Illumination measurements were made over a period that spanned several days near the Spring Equinox and Summer Solstice. Luminance readings were made simultaneously with a series of Li-Cor model LI-210SA photometric sensors. Campbell Scientific model CR10X data logger was used to collect the luminance data. As a result, lighting energy was reduced by 74%, with an annual energy cost savings of $3,066. Results show that a combination of illumination from daylight and the electric lighting system provide all spaces with the required illuminance in the TTF. NREL conducted a comfort analysis with respect to ASHRAE Standard 55-1992 (ASHRAE 1992), which specifies the combination of indoor space environment and personal factors.

3.5 Summary

Energy savings were first expected with the final design model. The site energy and cost savings were 42% and 53%, respectively, as compared to the benchmark (base-case) model. The base case model was remodeled with as-built characteristics to provide a better comparison for evaluating energy savings. It was estimated that the total site energy and cost savings were 41% and 52% less energy then the as-built base-case model when compared to as-built simulation results for a typical meteorological year. The predicted energy savings in the final design stage are almost the same as the results of post-occupancy evaluation with as-built simulation. If the plug loads were not included, the energy cost savings were 63% less then the code-compliant, base-case model. In fact, the receptacle loads were not part of the original criteria for the analysis.

4. CBF Building

The Chesapeake Bay Foundation (CBF) built the 31,000 sqft Philip Merrill Environment Center in Annapolis, Mayland, to serve as foundation headquarters. CBF incorporated high performance energy efficient features into the building to minimize its environmental effects on the bay. The report focuses on the monitoring and analysis of the building's overall performance.

4.1 Monitoring

NREL performed detailed long-term monitoring from 2001to 2002. They installed a permanent data acquisition system (DAS), which has two separate components: one for main building and a second for the conference pavilion. The weather data were also measured on top of the conference pavilion. The data loggers take measurements every 20 seconds and the report totaled or average results every 15 minutes, which is retrieved automatically every day. A custom computer program called "SortData" reads and cleans the raw data and then HPBAnalyzer, a custom data analysis application written by Brent Griffith in NREL, analyzed and visualized the results. Missing data were filled using an averaged curve developed for plug loads and using a regression model for determining propane energy use. Monitoring system uncertainty was estimated based on the manufacturer's data. Monitoring results were summarized for a one-year period and then broken down into monthly and daily periods.

4.2 Benchmark

The base-case model was developed using the EnergyPlus simulation program (Crawley et al. 2001), based on Appendix G of ASHRAE Standard 90.1-2001 (ASHRAE 2001). Some monitored data were used to provide inputs for modeling the base-case building reflected by as-built conditions. Measured weather data were processed for use with EnergyPlus. Some measured data were fixed to avoid problems. The on-site pyranometer measures global horizontal solar radiation and the Perez All-Weather Sky model (Perez 1992) was used to calculate the direct normal radiation. Cloud cover was not observed directly and so was inferred from solar radiation measurements with a method developed by Auer. Two types of schedules were developed from monitored data: a smoothed schedule to represent average conditions and a detailed calibration of internal gains from receptacles and process loads. EnergyPlus input for schedules were generated using the HPBAanalyzer, based on 15 minute data. Assembly R and U factor calculated from complete construction were used for envelope in the base-case model. From the climate and size of the CBF building, single-zone rooftop packaged unit with gas-fired heating and no economizer were selected for base case HVAC system. However, it seems that they also didn’t account for building thermal mass effect and HVAC equipment capacity that should be auto-sized from the simulation load of base case model.

4.3 As-built simulation

The as-built simulation model was not developed due to the complexity of the HVAC systems and the late addition of water source heat pumps in EnergyPlus.

4.4 Sub-systems analysis

Sub-systems were evaluated with monitoring results, including: the ground source heat pumps (ground loop supply and return temperature, and electricity measurements), natural ventilation (wind direction analysis), and photovoltaic system (measured electricity analysis and PV system simulation), and daylighting system (photometric measurement and average weekday profile of lighting electricity use).

4.5 Summary

Energy performance analysis was conducted after occupancy. The evaluation focused on the whole-building performance rather then individual building components. The evaluation period was November 2001 through November 2002. NREL compared the base-case (benchmark model) simulated results with the monthly metering of utilities to evaluate whole-building energy performance. They estimated energy savings with uncertainty levels (%) based on 98% of confidence interval. The site energy savings were (24.5 ± 14.1)% and cost energy savings were (12.1 ± 14.1)% when compared to the base-case (benchmark) model against utility bills. Before the building was constructed, the design team used a combination of simulation (TRACE 600) and offline analyses for natural ventilation and active solar systems to predict performance values in terms of building end-uses such as heating EUI, cooling EUI, lighting, plug load EUI, and PV power production. As a result, the measured data were lower than predicted because the performance predictions made during design development were optimistic. The deviation was mainly from plug loads and miscellaneous loads such as exterior lighting, mechanical room accessories, and the elevator, which were not accounted for in the original prediction.

5. BigHorn

The BigHorn Home Improvement Center in Silverthorne, Colorado, consists of an 18,400 sqft hardware store retail area and a 24,000 sqft warehouse. Silverthorne is a mountain community at an elevation of 8,720 ft. with long winters and short summers. It is a heating-dominated climate with over

10,000 (base 65 F) heating degree days. The building contains several energy efficient features, including: the smart envelope system for natural ventilation to meet all cooling loads, a hydronic radiant floor system with natural gas-fired boiler, and an energy management system to control the light, natural ventilation, and heating system. A transpired solar collector and gas radiant heater heat the warehouse. An 8.9 KW roof-integrated photovoltaic system offset electrical energy consumption.

5.1 Monitoring

Gas energy consumption was monitored through the monthly utility bills. Electrical energy consumption was recorded monthly by the utility company and every 15 minutes by the Data Acquisition System (DAS), which consists of data loggers and sensors, was designed to monitor all the data points. It was connected to a cellular phone for remote access and all the data storage and retrieval operations were automated. The expected accuracy of the sensors used in the monitoring system was determined from product specification. Individual electricity measurements were 0.5% based on the manufacturer's data. NREL expected the uncertainty of the annual performance metrics based on measured energy use to be ±1 %.

5.2 Benchmark

Design Baseline was developed using the DOE-2.1E simulation program in the design stage, based on typical code-compliant buildings that met the minimum requirements of the Federal Energy Code 10 CFR 435 (DOE 1995). The base-case model has the same size and function as the proposed design building. It a square building with windows distributed equally on all four sides. After the building was constructed, an as-built baseline model was developed, which reflects the size and functionality of the as-built building. However, it was created to just the thermal efficiency requirements of ASHRAE Standard 90.1-2001(ASHRAE 2001).

5.3 As-built simulation

As-built model was created to accurately reflect the as-built building. The plug loads, lighting display, and exterior lights were scheduled to match the measured energy consumption data as closely as possible for the calibration period. The operating schedules were set to match the measured energy data as closely as possible. Heating and ventilating systems were also designed to match the real building as closely as possible. The as-built model was next calibrated against the measured data with the TMY2 weather file for Eagle, Colorado, which was modified further to the temperature using WeatherMaker in the Energy-10 energy simulation program (NREL 2001). DataReader (Deru 2004) was used to calculate solar radiation and other data manipulations.

5.4 Sub-systems analysis

Sub-systems were evaluated, including: the space conditioning systems, lighting and daylighting systems, and photovoltaic system. There is no cooling system, no ventilation system, and the heating systems are radiant, which is the largest energy end use. Quantitative measurements were performed to better understand lighting based on the protocols developed as part of the IEA/SHC-Task 21 (Atif et al. 1997). One time, handheld illuminance measurements were taken in the warehouse and in the retail area. Short-term continuous illumination measurements were recorded in the retail area three times during the year. Luminance readings were taken at a height of 4ft, with Li-Cor model LI-250 Light Meter. For the PV System, additional measurements were taken for a more detailed evaluation, including: delivered AC production by the PV system, percentage of the building electric energy and demand offset by PV system, and actual performance compared to expected performance.

5.5 Summary

Energy performance was predicted by the optimized model and evaluated by as-built model with the same long-term average weather file. There was some difference in the model, including exterior lighting load and floor area. The results are compared on a per unit area basis. The predicted building site EUI is only 7.5% lower than the measured data, but the building source's EUI is 26 % lower due to the difference of anticipated electrical energy load. The design savings were predicted based on ASHRAE 90.1-1989 and 10 CFR 435, and the as-built simulation savings estimations use ASHRAE 90.1-2001 as the baseline building. Energy savings was first predicted with the proposed design model at the end of the design stage. It was calculated with the as-built simulation that the energy cost savings were 53% compared to the benchmark (base-case) model. Most of the energy savings were from an 80% reduction in the lighting energy and the elimination of fans. In addition, annual peak electrical demand in the as-built model was nearly 60% lower than in the as-built baseline model.

B6. Overall Summary of the Performance Evaluation performed by NREL

For the building performance evaluation, NREL performed continuous monitoring for long-term period, utility bill analysis, and computer simulation to develop code-compliant, base-case models and as-built simulation models. The as-built simulation models used to estimate energy savings as compared to the base-case (benchmark model) simulation, except for two buildings that had difficulties in modeling the as-built model due to a complex system and operation. Table 2 shows the summary of the performance evaluation methods and energy savings in each building. Each method is summarized as follows in terms of monitoring, benchmark model, as-built simulation, and sub-system analysis.

NREL used detailed long-term monitoring using permanent data acquisition system (DAS) or energy management system (EMS), which has some limitations to collect and store data due to lack of the storage capacity of the EMS. Monitoring systems uncertainty was estimated based on the manufacturer's data for all the buildings. Bad data and missing data were treated on a case-by-case method, using spreadsheets or programs developed.

All the energy savings were estimated based on a base-case (benchmark) model compliant with ASHRAE Standard 90.1 or Federal Energy Code (FEC) 10 CFR 435 (DOE 1995), which is similar to the ASHRAE Standard 90.1-1989 (ASHRAE 1989) with additional lighting requirements. However, modeling methods were not consistent in each case in terms of building shape, internal loads, and system operations. Furthermore, it seems that they didn't account for building thermal mass effect and auto-sized capacity of the HVAC equipment used for developing base-case (benchmark) model.

Most sites developed as-built simulation models to estimate energy savings as compared to base-case models. Most of the as-built simulation models were calibrated with measured data, including: plug loads, HVAC equipment and set point, and measured weather data. However, the calibration methods and parameters were also developed on a case-by-case basis. Uncertainty of calibration results was not evaluated. For the performance analysis of sub-systems, additional measurements and individual simulations were conducted. The sub-system evaluation focused on the individual system performance rather than energy savings related to whole-building energy performance.

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Table A.1 Summary of the Energy Performance Evaluation and Savings

	Oberlin	Zion	TTF	CBF	BigHorn
Site	Oberlin, Ohio	Southwest Utah	Golden, Colorado	Annapolis, Md.	Silverthorne, Colorado
Building Type	School	Visitor Center	Thermal Test Facility	Environmental Center	Home improvement Center
Building Size	13,600 sqft (Two stories)	8800 sqft (main) 2756 sqft (restroom)	10,000 sqft	31,000 sqft	18,400 sqft (retail) 24,000 sqft (warehouse)
Predicted Cost Savings (Predicted vs. Benchmark)	**Net zero site energy**	**80%**	**70%**	**50%**	**60%**
Measured Energy Savings (Measured vs. Benchmark)	16.4 kBtu/sqft	62%	42%	51%	35%
Site Energy Savings	47% (based on As-built simulation)	62 % (based on Measured Data)	42% (based on as-built simulation)	51% (based on measured Data)	35% (based on as-built simulation)
Energy Cost Savings	**35%** (based on utility bills)	**67%** (based on utility bills)	**52%** (based on as-built Simulation)	**51%** (based on utility bills)	**53 %** (based on as-built Simulation)
1. Benchmark Model	STANDARD 90.1-2001	STANDARD 90.1-1999	1995 FEC based on ASHRAE 1989	STANDARD 90.1-2001	STANDARD 90.1-2001
Simulation Program	DOE-2.1E	DOE-2.1E	DOE-2.1E	EnergyPlus	DOE-2.1E
Weather Data	TMY2	Measured Data from BAS system (with Global horizontal solar)	TMY2	Measured data with solar (Perez Sky Model for direct normal)	TMY2
Internal load & Schedule	As-built model	Measured data	ASHRAE 90.1-1989	Measured hourly data using HPBAnalyzer	As-built model
2. As-built Model	Yes	No	Yes	No	Yes
Simulation Program	DOE-2.1E	-	DOE-2.1E	-	DOE-2.1E
Weather Data	Measured data (TMY2)	-	Measured Data (TMY2)	-	Measured Data (Eagle TMY2)
_ Metheorological data	Site Measured Data	-		-	Adjusted TMY2 using Weathermaker
_ Solar data	Measured horizontal solar	-	Measured direct normal and horizontal solar	-	Measured horizontal and estimated direct normal and diffuse solar using DataReader (Deru, 2004)
Internal Load & Schedule	Assumed schedule but tuned with measured data	-	Adjusted lighting with measured data	-	Measured Data
Envelope	Effective R-value	-	As-built construction	-	R-Value
HVAC	Manufacturer performance data with some assumptions	-	Based on measured data and as-built drawings	-	As-built conditions
3. Whole Building Long Term Monitoring	Two Data loggers(Campbell)	BAS Systems	EMS systems	Two Data loggers	Data loggers
Data Period	2001-2003	2001-2002	1997-1999	2001-2002	2001-2003
Data Processing	Daily error checking with spreadsheet program	15 min. data	Data collection twice daily	**SortData and HPBAnalyzer**	15 min. data
Monitoring Points				40 points	15 points
_Whole building	Total consumption and PV production	Utility meter and PV system	Total consumption	Utility meter and PV system	Utility meter and PV system
_Sub-metering	HVAC, Light, and Equipment	HVAC, Light, and Equipment	HVAC, Light, Equipment, CO2, and hot water flow meter (Bloor door, tracer gas, STEM)	Heat pump, light and plug, ground supply and return water temp.	Pump, light, miscellaneous loads
4. Sub-systems Evaluations		Monitoring		Monitoring Results	
HVAC	Energy recovery ventilator (supply and exhaust side air temp.)	Trombe Wall and electric radiant ceiling panels	-	Ground source heat pumps (Ground loop supply and return water temp. and electricity measurement)	No Cooling system with natural vetilation
	Ground source heat pump (Capacity and COP reduction at typical ground source EWT)	Cooltower for natural ventilation (pump and fan energy use, water consumption, natural ventilation)	-	Natural Ventilation (Wind direction analysis)	Radiant heating system
PV System	Performance Simulation (PVSyst v3.2) Sandia Photovoltaic I-V Curve Tracer	Performance Simulation (PVSyst v3.2) Sandia Photovoltaic I-V Curve Tracer (King et al., 1998)	-	PV power genaration (measured and simulated)	PV Systems
Lighting and daylighting	Illuminance measurements (IEA/SHC Task 21 Monitoring Method) lighting saving calculations due to lighting and daylighting	Illuminance measurements (IEA/SHC Task 22 Monitoring Method) lighting saving calculations due to lighting and daylighting	Illuminance measurements (IEA/SHC Task 23 Monitoring Method)	Photometric measurement and average weekday profile of lighting electricity	Illuminance measurements Daily lighting load profile
Etc.	Wastewater Treatment (water pump, equipment, and exhaust fan)	Thermal Comfort (temp. measurement)	Thermal Comfort (ASHRAE Standard 55-1992)	-	-
Other ECMs	1. Natural ventilation	1. Overhangs	**1. Clear Story Windows**	**1. Operable Windows**	**1. Smart envelope**
	2. Massive building material		2. Two-stage evaporative cooling	2. Rainwater collector	2. Energy management system
	3. Energy management system		3. Overhangs	3. Desiccant wheel dehumidification	
			4. Thermal envelope		
Reference (Authors)	S.D.Pless and P.A. Torcellini	P.Torcellini, N. Long, S.Pless, and R. Judkoff	P.Torcellini, S.Pless, B. Griffith, and R. Judkoff	B. Griffith, M. Deru, P.Torcellini, and P. Ellis	M. Deru, P.Torcellini, and S. Pless

APPENDIX B

MONITORING CHANNELS AND PARAMETER SETS

Appendix B.1 includes channel information and verification for flow meter, RTD temperature sensor, and current transformer (CT). Each flow meter has a scale factor and a offset from the manufacturer, which was verified after installation as shown in Table B.1. Table B.2 shows the RTD temperature channels and verification results from on-site measurements. Logger readings (Amps) were verified with calculated values and on-site clammed readings for each Current Transformer (CT) channels as shown in Table B.3. Appendix B.2 includes parameter sets for each data logger, including integration period, watt channels, analog channels, and digital channels. Scale factor and offset were specified for watt channel and analog channels in the parameter set. Parameter set (PARSET) for each data logger consists of integration period, watt channels, analog channels, and digital channels. The data logger 215 (2546) has seven watt channels for MCC and chiller electricity and twelve analog channels for chilled water flow and temperature, condenser water flow and temperature, and hot water flow and temperature. Analog channels have scale a factor and an offset for each sensor after sensor calibration, which was verified as shown in Tables B.2 and B.3. PARSET for the Data logger 216 (2900) includes watt channels for whole-building electricity and digital channels for the conference center and the print shop. PARSET for the data logger 217 (2901) includes watt channels for 4th floor electricity use.

B1. Channel Information and Verification

Table B.1 Flow Meter Channels and Verification

Logger #	Channel Type	Chan	Description	Chid	Sensors Model	Scale Factor		Verification (GPM)			Remarks
						*Scale	Offset	Full Scale	Max Flow	Logger Reading	
215	Analog	A0	Chil 1 ChWS Flow	4484	ONICON FM F-1100	281.25	-225	900	744	713.3	*Scale (gpm/volt) = Full scale/3.2 V
		A5	Chil 2 ChWS Flow	4489	ONICON FM F-1110	281.25	-225	900	744	697	
		A10	HW Flow	4494	ONICON FM F-1111	93.75	-75	300	250	104	

Table B.2 RTD Temperature Channel and Verification

Logger #	Channel Type	Chan	Description	Chid	Sensors Model	Scale Factor		Wire Resistance	Verification (F)		Remarks
						Scale	*Offset		Local Gauge	Logger reading	
215	Analog	A1	Chil 1 ChWS Temp	4485	Pyromation RTD	1	-1.02	2.2 ohms	49	50 F	
		A2	Chil 1 ChWR Temp	4486	Pyromation RTD	1	-1.22	2.6	67	65.67	1000 OHM RTD (0.00385 Coefficient) *Offset (F) = (Wire resistance/ Coefficient) * 1.8
		A3	Cond 1 Sup Temp	4487	Pyromation RTD	1	-1.22	2.6	67	65.67	
		A4	Cond 1 Ret Temp	4488	Pyromation RTD	1	-0.98	2.1	68	67.46	
		A6	Chil 2 ChWS Temp	4490	Pyromation RTD	1	-1.31	2.8	46	43.7	
		A7	Chil 2 ChWR Temp	4491	Pyromation RTD	1	-1.03	2.4	50.19	49	
		A8	Cond 2 Sup Temp	4492	Pyromation RTD	1	-1.22	2.6	75	74.22	
		A9	Cond 2 Ret Temp	4493	Pyromation RTD	1	-1.12	2.4	78	78.12	
		A11	HW Sup temp	4495	Pyromation RTD	1	-0.75	1.6	190	19.35	
		A12	HW Ret temp	4496	Pyromation RTD	1	-1.08	2.3	-	185.74	

Table B.3 Current Transformer(CT) Channel and Verification

Logger #	Channel Type	Chan	Description	Chid	Sensors Model	Scale Factor	CT Secondary (mv)	Verification (Amps)			Remarks
								Calculated	Logger Reading	Clamped Reading	
215 (2546)	Watt	CT0	MCC Electric	4476	CT 4LS3	600A:333mV	308	554.9	566	581	
		CT1	MCC Electric	4477	CT 4LS3	600A:333mV	300	540	544	544	
		CT2	Chiller 1 Elec	4478	CT 4LS3	400A:333mV	187	224	216.2	220	
		CT3	Chiller 1 Elec	4479	CT 4LS3	400A:333mV	181	217	212	217	
		CT4	Chiller 2 Elec	4480	CT 4LS3	400A:333mV	173	207.8	207.1		
		CT5	Chiller 2 Elec	4481	CT 4LS3	400A:333mV	174	209.9	203.2		
		CT6	Chiller 4 Elec	4482	CT 4LS3	400A:333mV	-	-	-	-	Stand-by Chiller
		CT7	Chiller 4 Elec	4483	CT 4LS3	400A:333mV	-	-	-	-	
216 (2900)		CT0	Bldg Electric 1	4497	CT 4LN2	5A:333mV	53	637	626	644	
		CT1	Bldg Electric 1	4498	CT 4LN2	5A:333mV	50	600	572	638	
		CT2	Bldg Electric 1	4499	CT 4LN2	5A:333mV	53	636.6	599	656	
		CT3	Bldg Electric 2	4500	CT 4LN2	5A:333mV	71.4	857.6	841	856	
		CT4	Bldg Electric 2	4501	CT 4LN2	5A:333mV	69	828.8	910	841	
		CT5	Bldg Electric 2	4502	CT 4LN2	5A:333mV	68	816	823	838	
217 (2901)		CT0	4th Floor East	4506	CT 4LS3	400A:333mV	39	46.8	46.5	47	
		CT1	4th Floor East	4507	CT 4LS3	400A:333mV	45	54.05	53.6	54	
		CT2	4th Floor East	4508	CT 4LS3	400A:333mV	39	46.8	46.5	47	
		CT3	4th Floor Central	4509	CT 4LS3	400A:333mV	18	21.6	23.1	22.3	
		CT4	4th Floor Central	4510	CT 4LS3	400A:333mV	21	25.2	23.5	24.3	
		CT5	4th Floor Central	4511	CT 4LS3	400A:333mV	16.2	19.5	19.7	19	
		CT6	4th Floor West	4512	CT 4LS3	400A:333mV	16.2	19.5	19.7	19	
		CT7	4th Floor West	4513	CT 4LS3	400A:333mV	19.9	23.9	24.2	24.5	
		CT8	4th Floor West	4514	CT 4LS3	400A:333mV	18.2	21.86	22.8	21.3	
		CT9	East A phase	4515	CT 4LS3	400A:333mV	13	15	14.5	14	Summed XFMRS (all A phase)
			Central A phase		CT 4LS3	400A:333mV	7.8	9.4	9.8	9.2	
			West A phase		CT 4LS3	400A:333mV	8.9	10.7	10.1	9.7	
		CT10	East B phase	4516	CT 4LS3	400A:333mV	9.6	15	12.7	12	Summed XFMRS (all B phase)
			Central B phase		CT 4LS3	400A:333mV	9.1	10.9	10.6	10.6	
			West B phase		CT 4LS3	400A:333mV	10.1	12.1	12.2	12.2	
		CT11	East C phase	4517	CT 4LS3	400A:333mV	15.5	18.6	16.1	16	Summed XFMRS (all C phase)
			Central C phase		CT 4LS3	400A:333mV	8.2	9.8	9.8	9.6	
			West C phase		CT 4LS3	400A:333mV	10.1	12.1	12.2	12.2	
216	Digital	D0	Conf Center Elec	4503	CH IQ200 METER	KWH/Pulse	-	-	-	-	Utilizing KY pulse only (2kWh/pulse)
		D1	Senate Print shp	4504	CH IQ200 METER	kWH/Pulse	-	-	-	-	
		D2	TLC Print Shop	4505	CH IQ200 METER	kWH/Pulse	-	-	-	-	

B.2 Parameter Sets for the Data Loggers

********* Configuration for Logger: 2546 Parameter Set Code: A *********

----- INTEGRATION PERIODS -----

	AM												PM											
From:	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11
To:	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Flag:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mins:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

----- WATT CHANNELS -----

Chan	Description	STA	Load	Hi	Lo	VMult	Amps	Vlt	Amp	PR	KW	KVA	KWH	KVAH
CT 0	MCC ELECTRIC	ON	3P	A1	B1	1	600			0	*			
CT 1	MCC ELECTRIC	ON	3P	C1	B1	1	600			1	*			
CT 2	CHILLER 1 ELECT	ON	3P	A1	B1	1	400			2	*			
CT 3	CHILLER 1 ELECT	ON	3P	C1	B1	1	400			3	*			
CT 4	CHILLER 2 ELECT	ON	3P	A1	B1	1	400			4	*			
CT 5	CHILLER 2 ELECT	ON	3P	C1	B1	1	400			5	*			
CT 6	CHILLER 4 ELECT	ON	3P	A1	B1	1	400			6	*			
CT 7	CHILLER 4 ELECT	ON	3P	C1	B1	1	400			7	*			
CT 8		OFF	3P	C1	N1	1	100			8				
CT 9		OFF	3P	A1	N1	1	100			9				
CT10		OFF	3P	B1	N1	1	100			10				
CT11		OFF	3P	C1	N1	1	100			11				
CT12		OFF	3P	A1	N1	1	100			12				
CT13		OFF	3P	B1	N1	1	100			13				
CT14		OFF	3P	C1	N1	1	100			14				
CT15		OFF	3P	A1	N1	1	100			15				

Chan	Search String	Field Notes
CT 0		MCC ELECTRIC - A PHASE
CT 1		MCC ELECTRIC - C PHASE
CT 2		CHILLER 1 ELECTRIC - A PHASE
CT 3		CHILLER 1 ELECTRIC - C PHASE
CT 4		CHILLER 2 ELECTRIC - A PHASE
CT 5		CHILLER 2 ELECTRIC - C PHASE
CT 6		CHILLER 4 ELECTRIC - A PHASE EMERGENCY CHILLER
CT 7		CHILLER 4 ELECTRIC - C PHASE EMERGENCY CHILLER
CT 8		
CT 9		
CT 10		
CT 11		
CT 12		

********* Configuration for Logger: 2546 Parameter Set Code: A *********

----- ANALOG CHANNELS -----

Chan	Description	Search String	STA	Scale	Offset	Units	T	S	G
A 0	CHIL 1 CHWS FLOW		ON	281.25	-225	Volts DC	*		
A 1	CHIL 1 CHWS TEMP		ON	1	-1.02	Deg F	*		
A 2	CHIL 1 CHWR TEMP		ON	1	-.94	Deg F	*		
A 3	COND 1 SUP TEMP		ON	1	-1.22	Deg F	*		
A 4	COND 1 RET TEMP		ON	1	-.98	Deg F	*		
A 5	CHIL 2 CHWS FLOW		ON	281.25	-225	Volts DC	*		
A 6	CHIL 2 CHWS TEMP		ON	1	-1.31	Deg F	*		
A 7	CHIL 2 CHWR TEMP		ON	1	-1.03	Deg F	*		
A 8	COND 2 SUP TEMP		ON	1	-1.22	Deg F	*		
A 9	COND 2 RET TEMP		ON	1	-1.12	Deg F	*		
A10	HW FLOW		ON	93.75	-75	Volts DC	*		
A11	HW SUP TEMP		ON	1	-.75	Deg F	*		
A12	HW RET TEMP		ON	1	-1.08	Deg F	*		
A13			OFF	1	0				
A14			OFF	1	0				
A15	NOT USED!		OFF	-999	-999				

Chan	CType	Field Notes
A 0	4-20ma	CHILLER 1 CHWS FLOW - ONICON FM 0-1200 GPM
A 1	1K RTD	CHILLER 1 CHWS TEMP - 1000 OHM RTD
A 2	1K RTD	CHILLER 1 CHWR TEMP - 1000 OHM RTD
A 3	1K RTD	CONDENSER 1 SUPPLY TEMP - 1000 OHM RTD
A 4	1K RTD	CONDENSER 1 RETURN TEMP - 1000 OHM RTD
A 5	4-20ma	CHILLER 2 CHWS FLOW - ONICON FM 0-1200 GPM
A 6	1K RTD	CHILLER 2 CHWS TEMP - 1000 OHM RTD
A 7	1K RTD	CHILLER 2 CHWR TEMP - 1000 OHM RTD
A 8	1K RTD	CONDENSER 2 SUPPLY TEMP - 1000 OHM RTD
A 9	1K RTD	CONDENSER 2 RETURN TEMP - 1000 OHM RTD
A10	4-20ma	HOT WATER FLOW - ONICON FM 0-400 GPM
A11	1K RTD	HOT WATER SUPPLY TEMP - 1000 OHM RTD
A12	1K RTD	HOT WATER RETURN TEMP - 1000 OHM RTD
A13	OFF	
A14	OFF	R.E. JOHNSON STATE BUILDING, AUSTIN TEXAS
A15	OFF	LOGGER PHONE #: (512) SITE #: 215

********* Configuration for Logger: 2900   Parameter Set Code: A *********

----- INTEGRATION PERIODS -----

	AM												PM											
From:	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11
To:	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Flag:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mins:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

----- WATT CHANNELS -----

Chan	Description	STA	Load	Hi	Lo	VMult	Amps	Vlt	Amp	PR	KW	KVA	KWH	KVAH
CT 0	BLDG ELECTRIC 1	ON	3P	A1	N1	1	4000			0	*			
CT 1	BLDG ELECTRIC 1	ON	3P	B1	N1	1	4000			1	*			
CT 2	BLDG ELECTRIC 1	ON	3P	C1	N1	1	4000			2	*			
CT 3	BLDG ELECTRIC 2	ON	3P	A2	N2	1	4000			3	*			
CT 4	BLDG ELECTRIC 2	ON	3P	B2	N2	1	4000			4	*			
CT 5	BLDG ELECTRIC 2	ON	3P	C2	N2	1	4000			5	*			
CT 6		OFF	3P	A1	N1	1	100			6				
CT 7		OFF	3P	B1	N1	1	100			7				
CT 8		OFF	3P	C1	N1	1	100			8				
CT 9		OFF	3P	A1	N1	1	100			9				
CT10		OFF	3P	B1	N1	1	100			10				
CT11		OFF	3P	C1	N1	1	100			11				
CT12		OFF	3P	A1	N1	1	100			12				
CT13		OFF	3P	B1	N1	1	100			13				
CT14		OFF	3P	C1	N1	1	100			14				
CT15		OFF	3P	A1	N1	1	100			15				

Chan	Search String	Field Notes
CT 0		5A CTS ON SECONDARY OF A PHASE PRIMARY 1 CT
CT 1		5A CTS ON SECONDARY OF B PHASE PRIMARY 1 CT
CT 2		5A CTS ON SECONDARY OF C PHASE PRIMARY 1 CT
CT 3		5A CTS ON SECONDARY OF A PHASE PRIMARY 2 CT
CT 4		5A CTS ON SECONDARY OF B PHASE PRIMARY 2 CT
CT 5		5A CTS ON SECONDARY OF C PHASE PRIMARY 2 CT
CT 6		
CT 7		
CT 8		
CT 9		R.E. JOHNSON CAPITOL BUILDING, AUSTIN, TX
CT10		LOGGER LOCATED IN MAIN ELECTRICAL ROOM-LOWER LEVEL
CT11		LOGGER PH#: (512) SITE #:216
CT12		
CT13		

********* Configuration for Logger: 2900 Parameter Set Code: A *********

----- DIGITAL CHANNELS -----

Chan	Description	Search String	STA	Scale	Units	TSR	AVG	RTS
D 0	CONF CENTER ELEC		ON	2	kwh	*		
D 1	SENATE PRINT SHP		ON	2	kwh	*		
D 2	TLC PRINT SHOP		ON	2	kwh	*		
D 3			OFF	1				
D 4			OFF	1				
D 5			OFF	1				
D 6			OFF	1				
D 7			OFF	1				
D 8			OFF	1				
D 9			OFF	1				
D10			OFF	1				
D11			OFF	1				
D12			OFF	1				
D13			OFF	1				
D14			OFF	1				
D15			OFF	1				

Chan	Field Notes
D 0	CONFERENCE CENTER - CH IQ200 METER - KY (BKR LABELED CCH METERING)
D 1	SENATE PRINT SHOP - CH IQ200 METER - KY (BKR LABELED PSH METERING)
D 2	TLC PRINT SHOP - CH IQ 200 METER - KY (BKR LABELED DPT METERING)
D 3	
D 4	
D 5	
D 6	
D 7	
D 8	
D 9	
D10	
D11	
D12	

Description	Channel	TSR Measurement #
BLDG ELECTRIC 1	KW 0	0
BLDG ELECTRIC 1	KW 1	0
BLDG ELECTRIC 1	KW 2	0
BLDG ELECTRIC 2	KW 3	0
BLDG ELECTRIC 2	KW 4	0
BLDG ELECTRIC 2	KW 5	0
CONF CENTER ELEC	DIG 0	0
SENATE PRINT SHP	DIG 1	0
TLC PRINT SHOP	DIG 2	0

********* Configuration for Logger: 2901 Parameter Set Code: A *********

----- INTEGRATION PERIODS -----

	AM												PM											
From:	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11
To:	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Flag:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mins:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

----- WATT CHANNELS -----

Chan	Description	STA	Load	Hi	Lo	VMult	Amps	Vlt	Amp	PR	KW	KVA	KWH	KVAH
CT 0	4TH FLOOR EAST	ON	3P	A1	N1	1	400			0	*			
CT 1	4TH FLOOR EAST	ON	3P	B1	N1	1	400			1	*			
CT 2	4TH FLOOR EAST	ON	3P	C1	N1	1	400			2	*			
CT 3	4TH FLOOR CENTRL	ON	3P	A1	N1	1	400			3	*			
CT 4	4TH FLOOR CENTRL	ON	3P	B1	N1	1	400			4	*			
CT 5	4TH FLOOR CENTRL	ON	3P	C1	N1	1	400			5	*			
CT 6	4TH FLOOR WEST	ON	3P	A1	N1	1	400			6	*			
CT 7	4TH FLOOR WEST	ON	3P	B1	N1	1	400			7	*			
CT 8	4TH FLOOR WEST	ON	3P	C1	N1	1	400			8	*			
CT 9	SUMMED XFMRS	ON	3P	A1	N1	1	1200			9	*			
CT10	SUMMED XFMRS	ON	3P	B1	N1	1	1200			10	*			
CT11	SUMMED XFMRS	ON	3P	C1	N1	1	1200			11	*			
CT12		OFF	3P	A1	N1	1	100			12				
CT13		OFF	3P	B1	N1	1	100			13				
CT14		OFF	3P	C1	N1	1	100			14				
CT15		OFF	3P	A1	N1	1	100			15				

Chan	Search String	Field Notes
CT 0		
CT 1		
CT 2		
CT 3		
CT 4		
CT 5		SUMMED TRANSFORMERS FROM ALL WINGS TO DEDUCT FROM BASE
CT 6		LIGHTING LOAD
CT 7		
CT 8		R.E. JOHNSON LEGISLATIVE BUILDING
CT 9		LOGGER LOCATED IN 4TH FLOOR TELECOMM ROOM
CT 10		SITE # 217 DC LOOPED TO SITE # 216 SN 2900
CT 11		PHONE # (512) 936-0621

********* Configuration for Logger: 2901 Parameter Set Code: A *********

----- ANALOG CHANNELS -----

Chan	Description	Search String	STA	Scale	Offset	Units	T	S	G
A 0	SOLAR - WEST		ON	376.07	-293.45	Volts DC	*		
A 1	SOLAR - SOUTH		ON	393.67	-334.37	Volts DC	*		
A 2			OFF	1	0				
A 3			OFF	1	0				
A 4			OFF	1	0				
A 5			OFF	1	0				
A 6			OFF	1	0				
A 7			OFF	1	0				
A 8			OFF	1	0				
A 9			OFF	1	0				
A10			OFF	1	0				
A11			OFF	1	0				
A12			OFF	1	0				
A13			OFF	1	0				
A14			OFF	1	0				
A15	NOT USED!		OFF	-999	-999				

Chan	CType	Field Notes
A 0	4-20ma	LOCATED IN CONFERENCE ROOM 4.411 ON 4TH FLOOR - WEST WINDOW
A 1	4-20ma	LOCATED IN CONFERENCE ROOM 4.411 ON 4TH FLOOR - SOUTH WINDOW
A 2	OFF	
A 3	OFF	
A 4	OFF	
A 5	OFF	
A 6	OFF	
A 7	OFF	
A 8	OFF	
A 9	OFF	
A10	OFF	
A11	OFF	
A12	OFF	
A13	OFF	
A14	OFF	
A15	OFF	

APPENDIX C

MEASURED WEATHER DATA

This appendix includes a summary of the missing data and time-series plots of the hourly measured data before and after the filling gap as shown in Figures C.1 through C.22.

C.1 Summary of Missing Data

Missing data for less than 6 hours were filled by linear interpolation while missing data for more than 6 hours were filled by replacing with those from adjacent weather station called ASU as shown in Table C.1.

Table C.1 Summary of Missing Weather Data

Station Name	Measured data	# of missing data hours (less than 6 hours)	# of missing data hours (more than 6 hours)
NREL	Global Radiation (W/m^2)	0	0
	Direct Normal Radiation (W/m^2)	0	0
	Diffuse Radiation (W/m^2)	0	0
NOAA	Dry-bulb Temp. (F)	12	3
	Wet-bulb Temp. (F)	14	3
	Dew Point Temp. (F)	12	3
	Wind Speed (mph)	13	3

C.2 Time Series Plots before and after Filling Gap or Bad Data

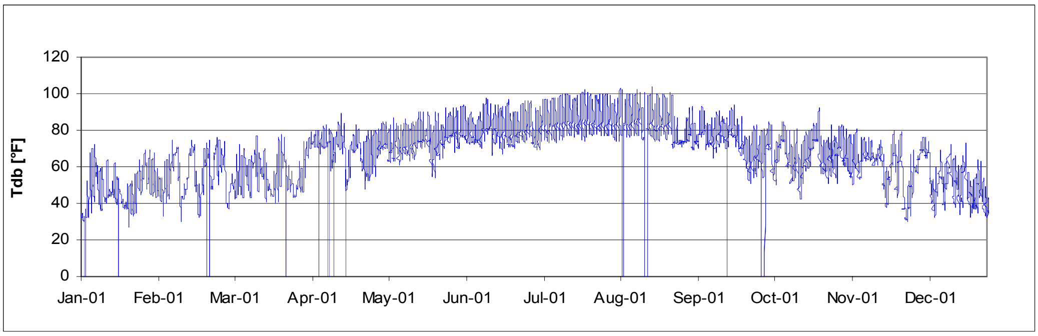


Figure C.1 *2001 Austin dry-bulb temperature (N0AA).*

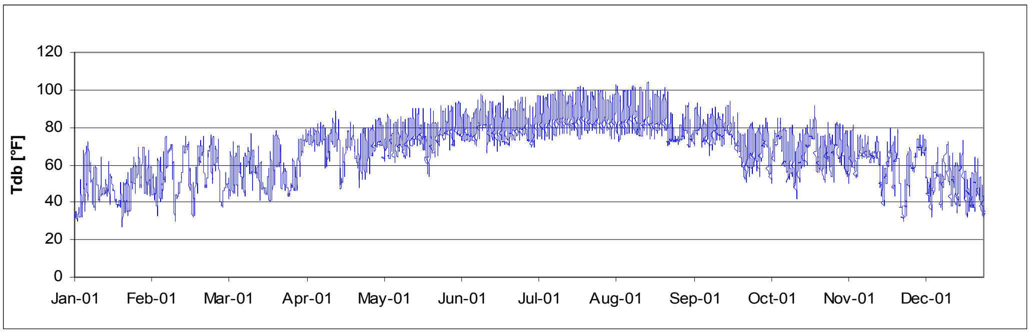


Figure C.2 *2001 Austin dry-bulb temperature (N0AA) after filling gap.*

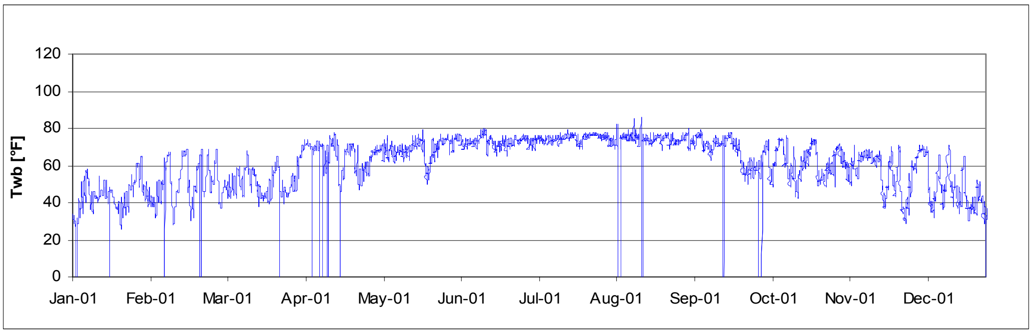


Figure C.3 *2001 Austin wet-bulb temperature (N0AA).*

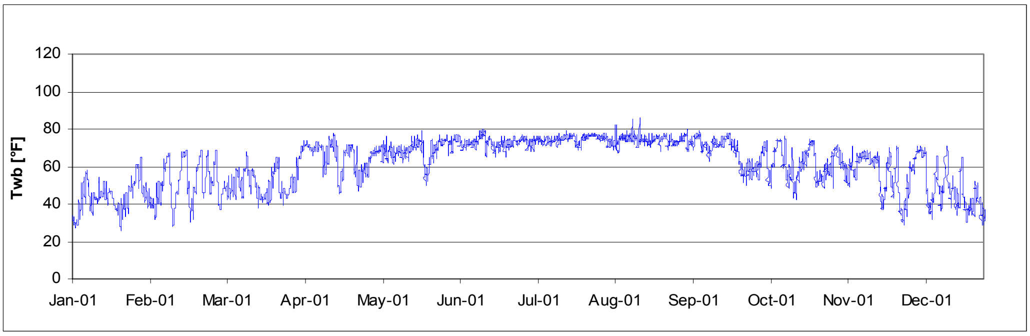


Figure C.4 *2001 Austin wet-bulb temperature (N0AA) after filling gap.*

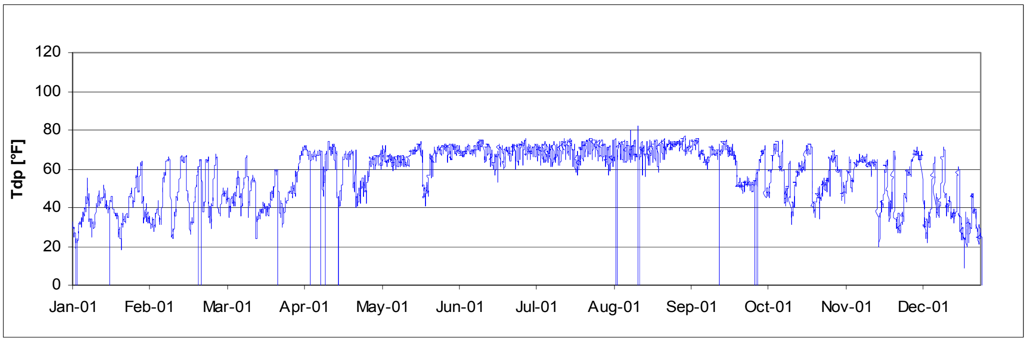


Figure C.5 *2001 Austin dew-point temperature (N0AA).*

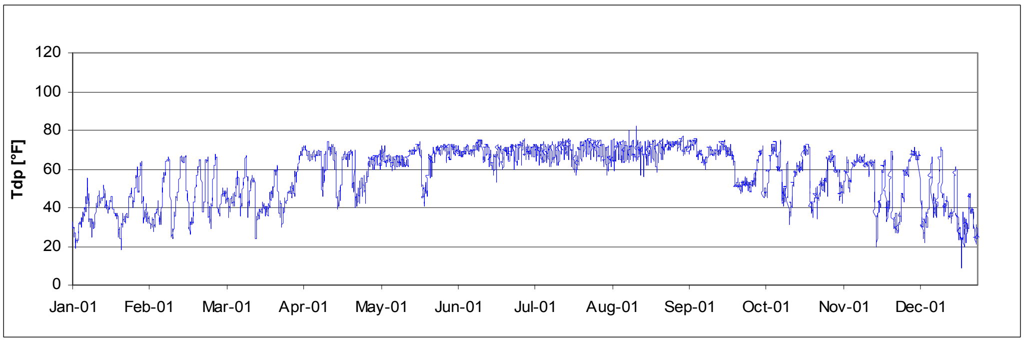


Figure C.6 *2001 Austin dew-point temperature (N0AA) after filling gap.*

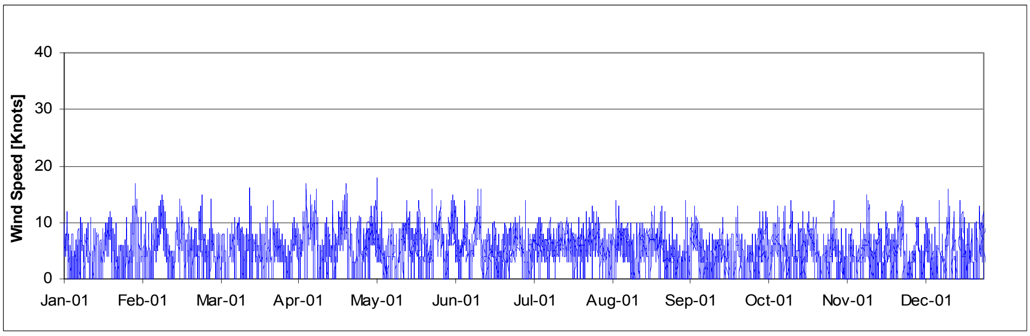


Figure C.7 *2001 Austin wind speed (N0AA).*

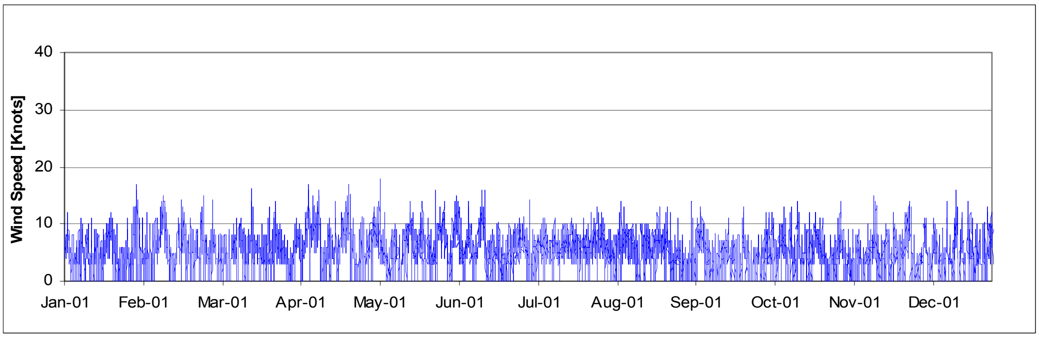


Figure C.8 *2001 Austin wind speed (N0AA) after filling gap.*

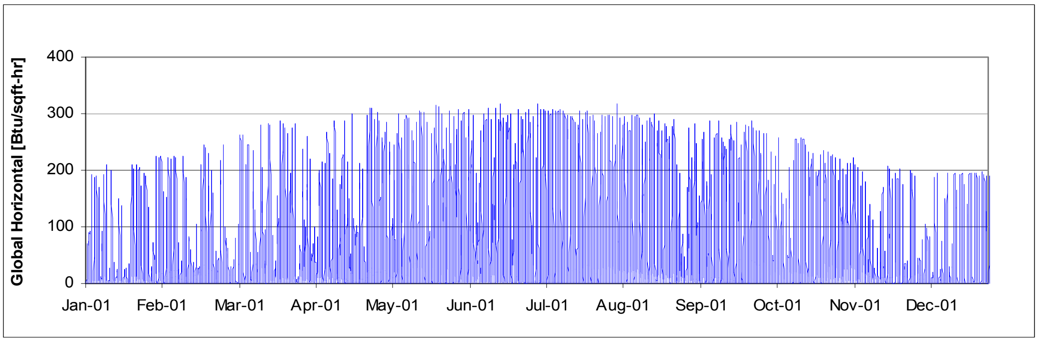


Figure C.9 *2001 Austin global horizontal solar radiation (NREL).*

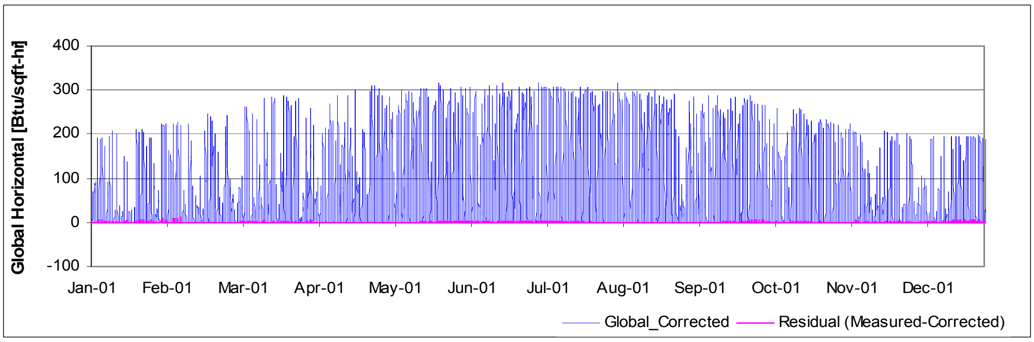


Figure C.10 *2001 Austin corrected global horizontal solar radiation (NREL) with residual.*

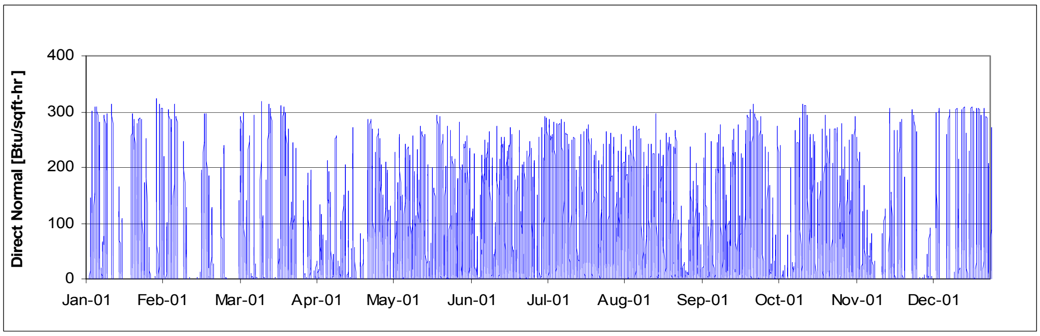


Figure C.11 *2001 Austin direct normal solar radiation (NREL).*

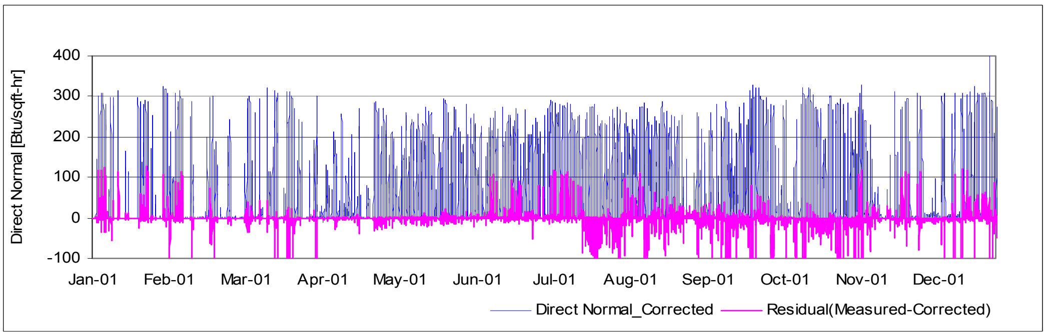


Figure C.12 *2001 Austin corrected direct normal solar radiation (NREL) with residual.*

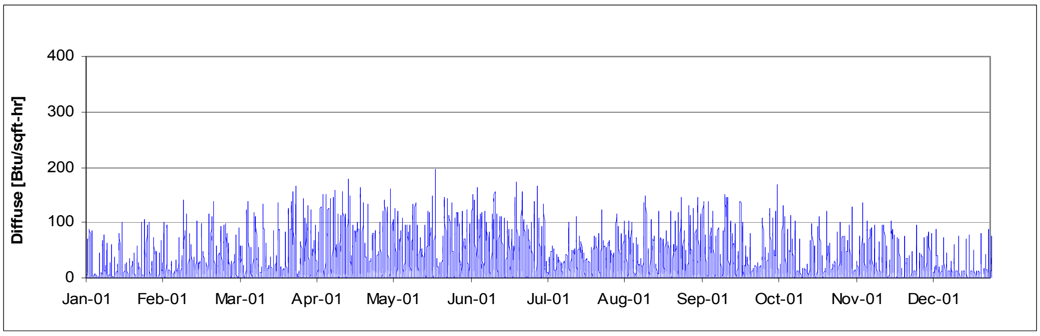


Figure C.13 *2001 Austin diffuse solar radiation (NREL).*

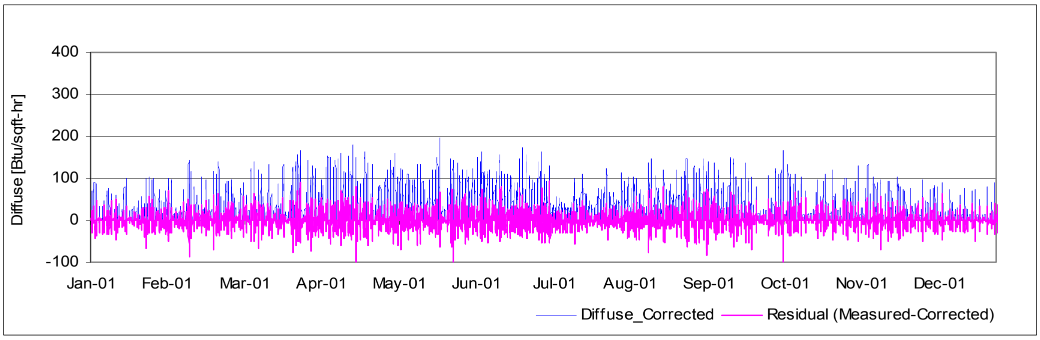


Figure C.14 *2001 Austin corrected diffuse solar radiation (NREL) with residual.*

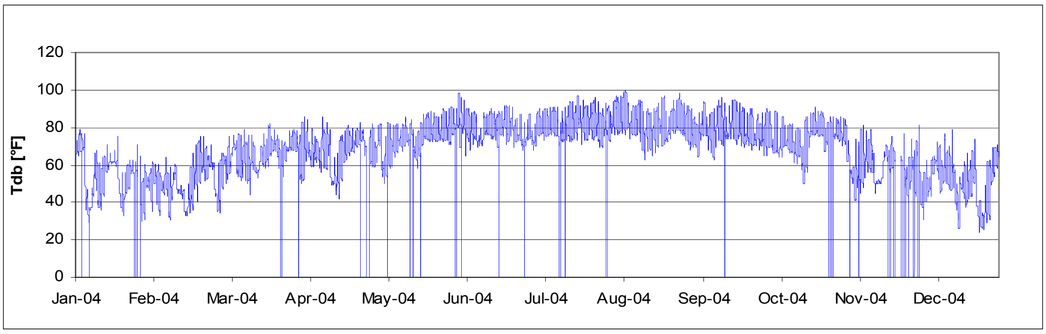


Figure C.15 *2004 Austin dry-bulb temperature (NOAA).*

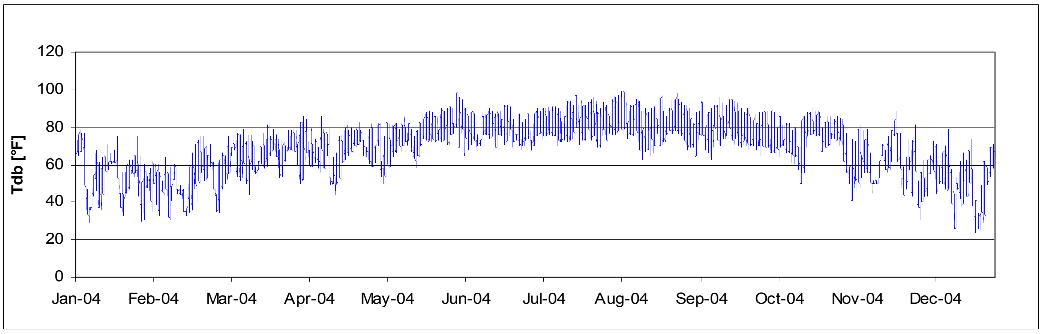


Figure C.16 *2004 Austin dry-bulb temperature (NOAA) after filling gap.*

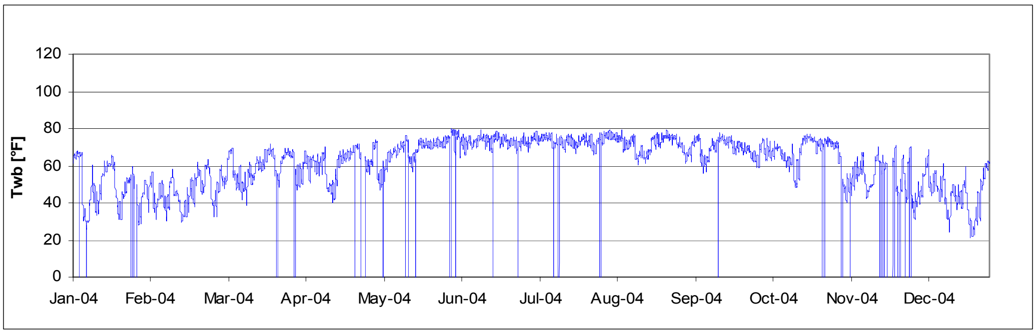


Figure C.17 *2004 Austin wet-bulb temperature (NOAA).*

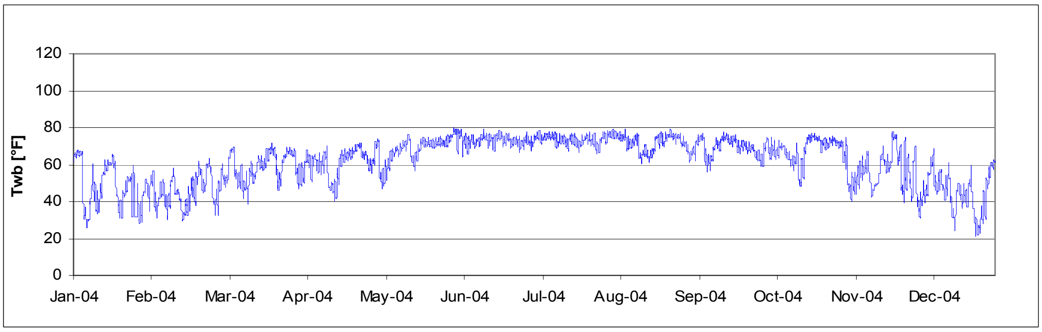


Figure C.18 *2004 Austin wet-bulb temperature (NOAA) after filling gap.*

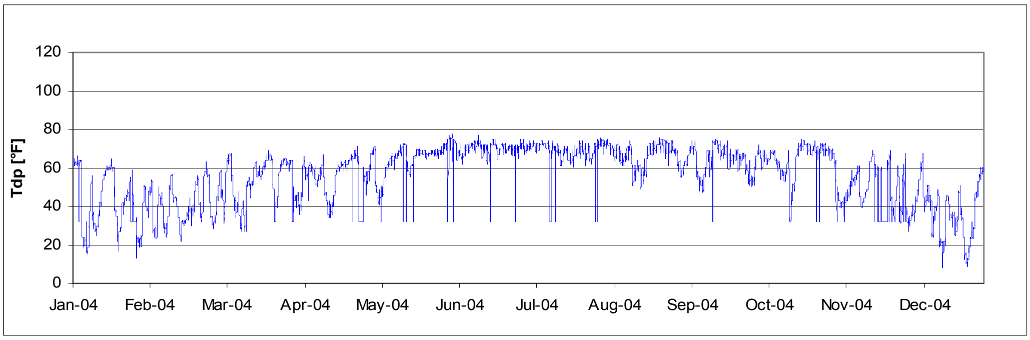


Figure C.19 *2004 Austin dew-point temperature (NOAA).*

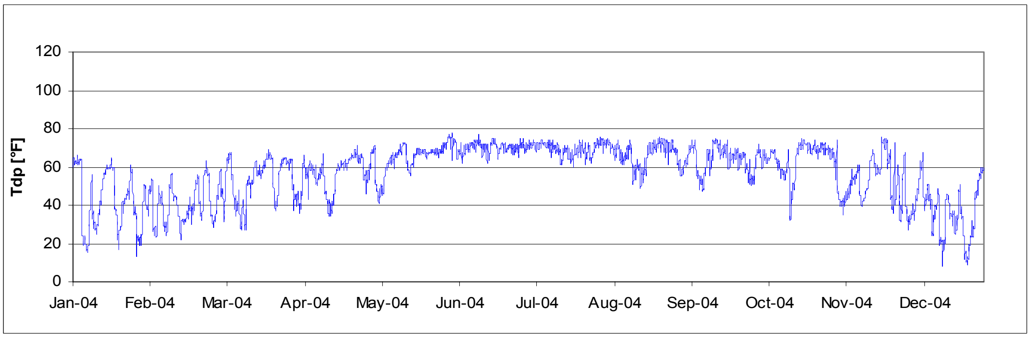


Figure C.20 *2004 Austin dew-point temperature (NOAA) after filling gap.*

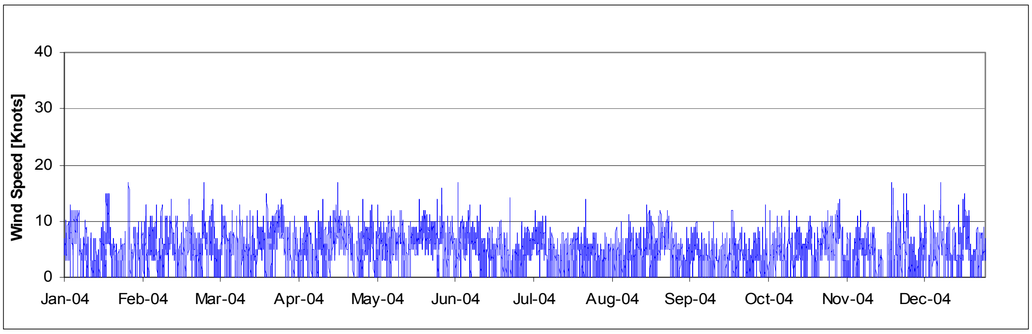


Figure C.21 *2004 Austin wind speed temperature (NOAA).*

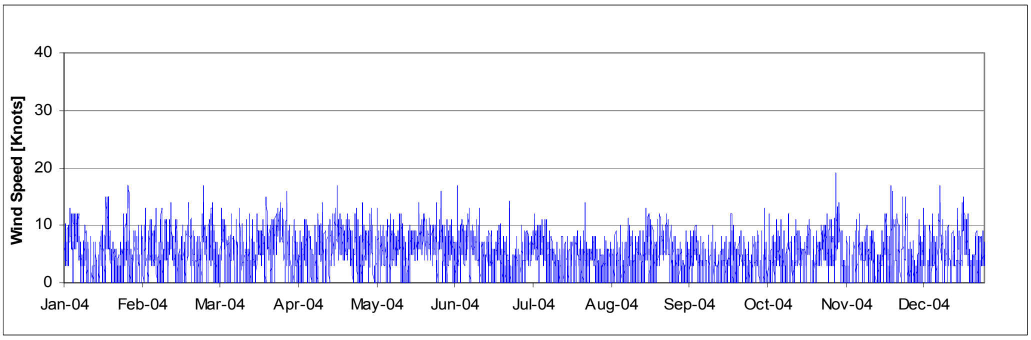


Figure C.22 *2004 Austin wind speed temperature (NOAA) after filling gap.*

APPENDIX D

MEASURED ENERGY DATA

This appendix presents monitoring channel information and measured data plots of the Robert E. Johnson state office building for the periods of January 1, 2001 through December 31, 2001 and January 1, 2004 through December 31, 2004. These two years of measured data revealed that the energy consumption characteristics were very useful in calibrating the as-built simulation of the case-study building. Table D.1 shows the description of the monitoring channels description and their equation, including: 1) The whole-building electricity (WBE) use including motor control center (MCC) electricity and other weather independent electric use (WBE-MCC); 2) The electricity use of the two chillers and the thermal energy use with chiller water flow, chilled water supply and return temperature, and condenser water supply and return temperature; 3) The boiler energy use with hot water flow and supply and return temperature, 4) The electricity use monitored with three independent meters for the conference center, the senate print shop, and the TLC print shop; 5) The 4^{th} floor electricity use including lighting and receptacle electricity use, which has been used to determine the typical electric load profile for the DOE-2 simulation in this study; and finally, 6) Solar radiation data collected to verify the low-E glazing.

Table D.1 Monitoring Channel Description

Items	Description	Unit	Channels	Remarks	
WBE	Whole Building Electricity	kWh/h	Building Electricity 1 Phase A (ch4497)	WBE 1 (Phase A+B+C)	Figure D.1
			Building Electricity 1 Phase B (ch4498)		
			Building Electricity 1 Phase C (ch4499)		
			Building Electricity 2 Phase A (ch4500)	WBE 2 (Phase A+B+C)	
			Building Electricity 2 Phase B (ch4501)		
			Building Electricity 2 Phase C (ch4502)		
MCC	Motor Control Center	kWh/h	MCC Electric Phase A (ch4476)	Phase A + Phase C	Figure D.1
			MCC Electric Phase C (ch4477)		
WBE – MCC		kWh/h	WBE – MCC	Weather independent electric use (Lighting, receptacles & others)	Figure D.2
Chillers	Chiller #1	kWh/h	Electricity Phase A (ch4478)	Phase A + Phase C	Figure D.3 Figure D.4
			Electricity Phase C (ch4479)		
		kBtu/h	User Defined Channel (ch4520)	GPH * (supply- return) temp)/2	Figure D.5
		GPH	Chilled Water Flow (ch4484)	-	Figure D.9
		F	Chilled Water Supply Temp. (ch4485)	-	Figure D.6
		F	Chilled Water Return Temp. (ch4486)	-	
	Chiller #2	kWh/h	Electricity Phase A (ch4480)	Phase A + Phase C	Figure D.3 Figure D.4
			Electricity Phase C (ch4481)		
		kBtu/h	User Defined Channel (ch4521)	GPH * (supply- return) temp)/2	Figure D.5
		GPH	Chilled Water Flow (ch4489)	-	Figure D.9
		F	Chilled Water Supply Temp. (ch4490)	-	Figure D.7
		F	Chilled Water Return Temp. (ch4491)	-	Figure D.7
	Chiller #3	-	No Channels	No sensors installed	-
Pumps		kWh/h	MCC- Chillers	Chiller pumps and others	Figure D.3
Boiler		kBtu/h	User Defined Channel (ch4522)	GPH * (supply- return) temp)/2	Figure D.10
		GPH	Hot Water Flow (ch4494)	-	Figure D.12
		F	Hot Water Supply Temperature (ch4495)	-	Figure D.11
		F	Hot Water Return Temperature (ch4496)	-	
Conference Center		kWh/h	Ch4503	-	Figure D.13
Senate Print Shop		KWh/h	Ch4504	-	Figure D.14
TLC Print Shop		kWh/h	Ch4505	-	Figure D.15
4th Floor	The 4th Floor Electric Energy Use	kWh/h	East (ch4506+ch4507+ch4508)	Light and Receptacles Electricity Use	Figure D.16
			Central (ch4509+ch4510+ch4511)		
			West (ch4512+ch4513+ch4514)		
			XFMRS (ch4515+ch4516+ch4517)	Receptacle Electricity Use	Figure D.17
			(East +Central + West) – XFMRS	Lighting Electricity Use	Figure D.18
	Solar Radiation	W/m^2	West Window (ch4518)	Solar Radiation trough Low-e Window	Figure D.20 Figure D.21
			South Window (ch4519)		

D1. Time Series Plots of the 2001 and 2004 Measured Data

Figure D.1 shows the whole-building electricity (WBE) and motor control center (MCC) electricity use for the REJ building from January 1, 2001 to December 31, 2001 and from January 1, 2004 to December 31, 2004. As shown in Figures D.3 through D.9, there were no measured data for the new chiller #3, which was installed in 2003. In 2001, chiller #1 was operated as a primary chiller and chiller #2 as a secondary chiller. However, chiller #1 had been shut down since new chiller #3 installed. In Figure D.1, the whole-building electricity use is shown along with the electricity use of the motor control center (MCC), which includes all the chiller electricity use and the electricity use of the associated equipment such as pumps and fans. Whole-building electricity use varied from about 750 kWh/h in the winter to about 1300 kWh/h in the summer. This variation is due to the load from the cooling plant as shown in Figure D.3. The pumps electricity use shows relatively constant for the entire period of the measured year, especially in the summer. Figures D.10 and D.11 show the measured heating energy use and hot water supply and return temperature with residual, respectively. Several periods of hot water energy use can be grouped due to operational changes and bad data.

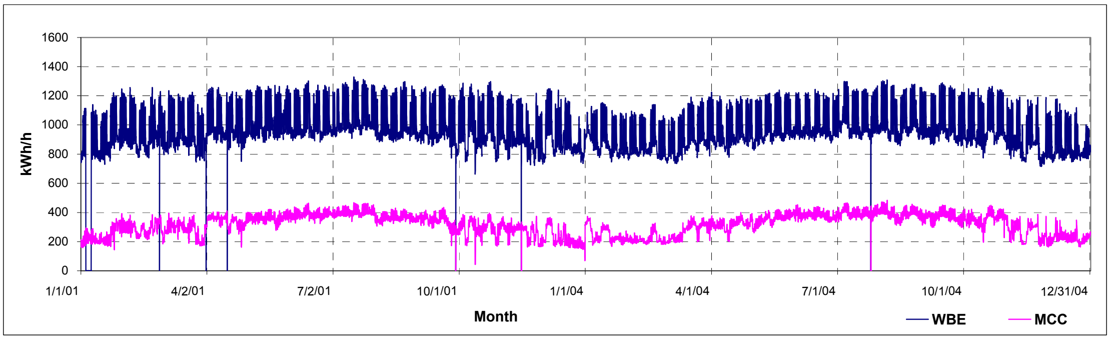


Figure D.1 *2001 and 2004 measured whole-building and motor control center electricity use.*

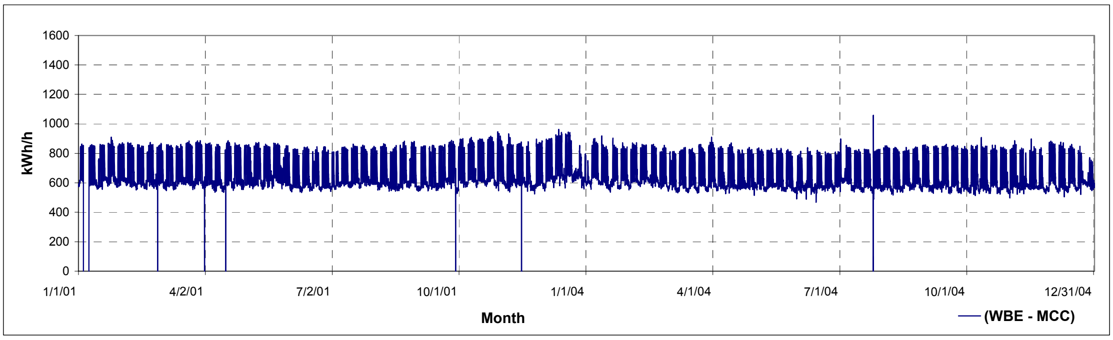


Figure D.2 *2001 and 2004 measured WBE-MCC electricity use.*

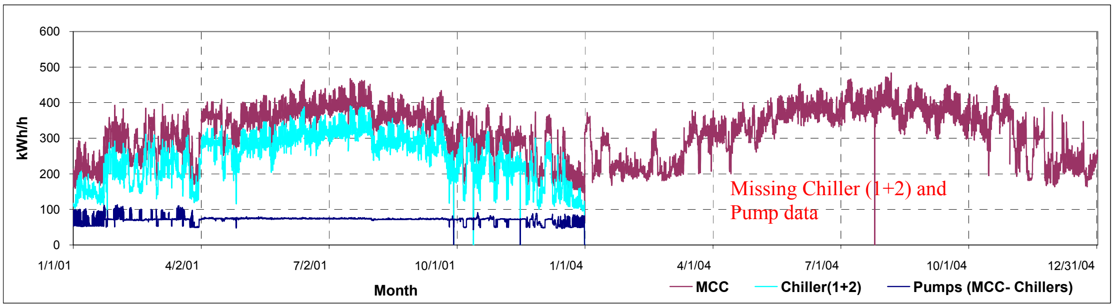


Figure D.3 *2001 and 2004 measured motor control center, chillers (1+2), and pumps(MCC-Chillers) electricity use.*

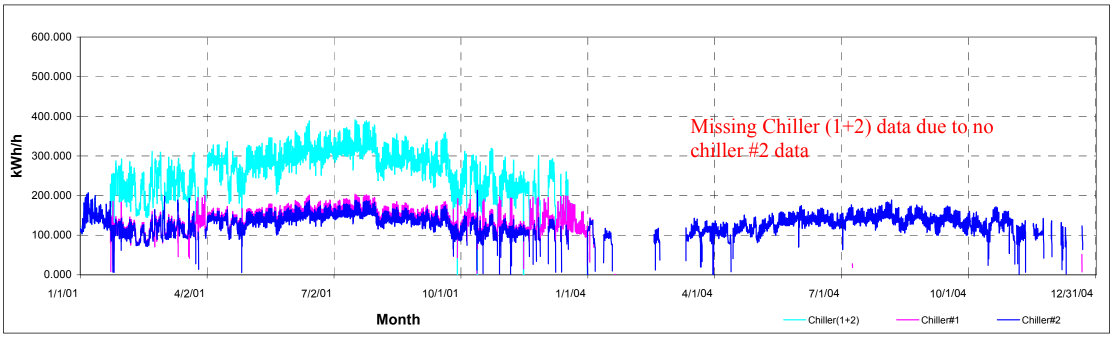


Figure D.4 *2001 and 2004 measured chiller# 1, chiller#2, and chiller # (1+2) electricity use.*

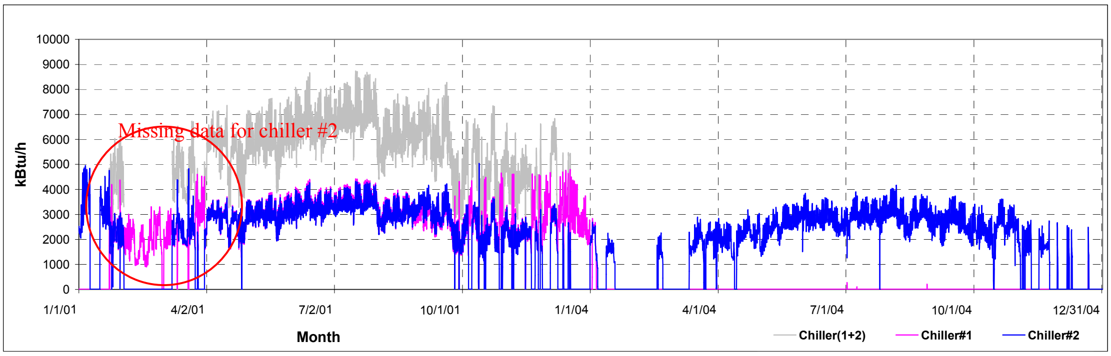


Figure D.5 *2001 and 2004 measured cooling energy use from chiller#1, chiller#2, and chiller (1+2).*

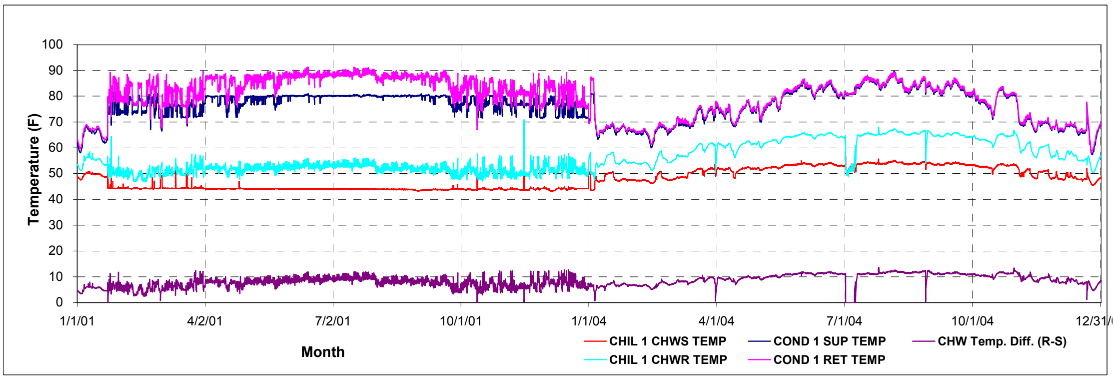


Figure D.6 *2001 and 2004 measured chiller #1 chilled and condenser water temperature.*

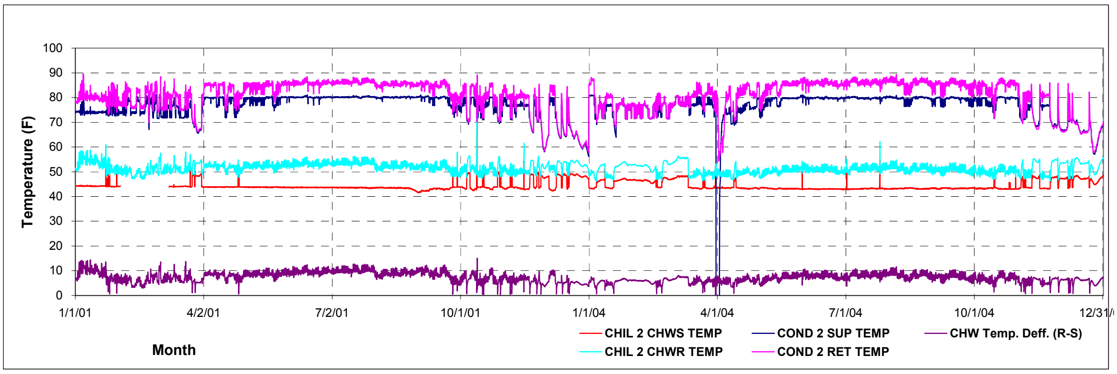


Figure D.7 *2001 and 2004 measured chiller #2 chilled and condenser water temperature.*

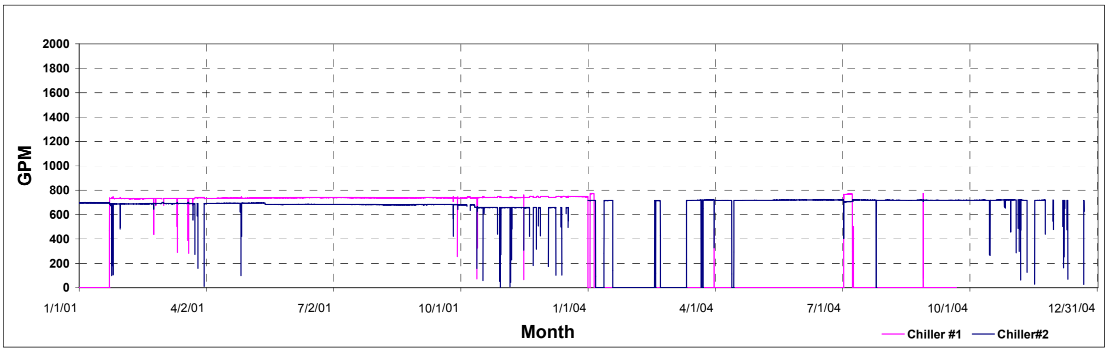


Figure D.8 *2001 and 2004 measured chiller #1 and chiller #2 chilled water flow.*

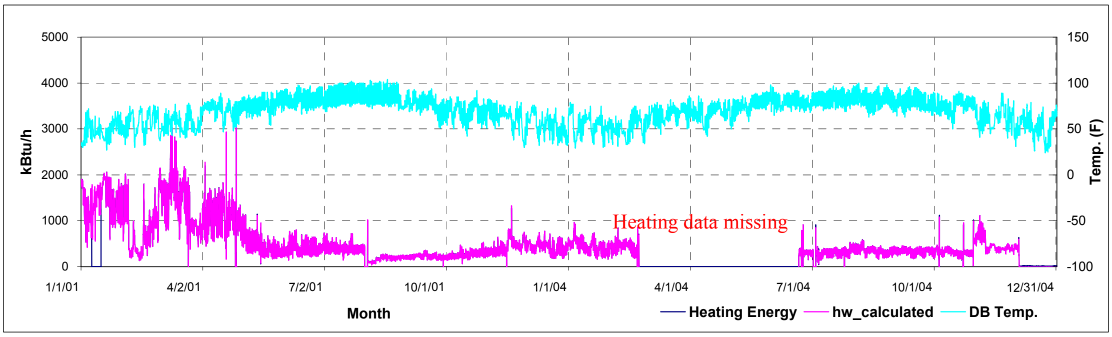


Figure D.9 *2001 and 2004 measured heating energy use and dry-bulb temperature.*

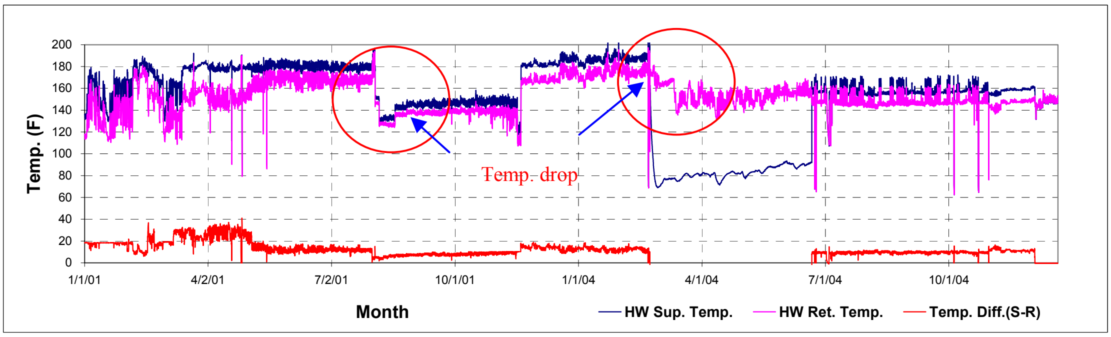


Figure D.10 *2001 and 2004 measured hot water supply and return temperature.*

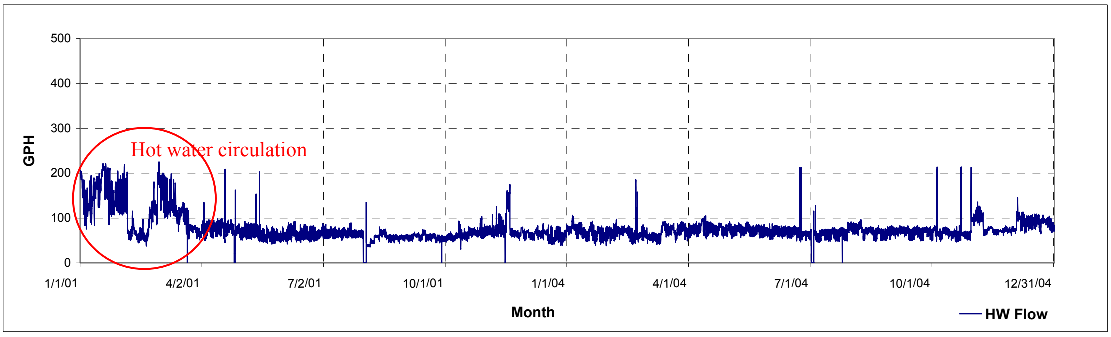


Figure D.11 *2001 and 2004 measured hot water flow.*

D. 2 Weekday and Weekend Loads Profiles and Diversity Factors

Appendix D.2 includes the typical load shapes developed from the measured data to represent the typical load day-types for weekday and weekend schedules in terms of whole-building lighting and receptacle loads and other independent loads. The ASHRAE 1093-RP Diversity Factor Toolkit was used to develop the typical load profiles from the measured data of the REJ building. Output tables include hourly values in each percentile group. The hourly values of 50th percentile in the day-type plot were used to represent the appropriate loads in the DOE-2 as-built simulation program. Figure D.12 to D.15 represent the 2001 and 2004 whole–building lighting and receptacle loads for weekday and weekend day-types expressed as percentile. Tables D.2 and D.3 specify the weekday and weekend diversity factors for the 2001 and 2004 whole-building lighting and receptacle loads (WBE-MCC). Figures D.16 to D.19 represent the 2001 and 2004 typical (4^{th} floor) lighting electricity use for weekday and weekend day-types expressed as percentile. Tables D.4 and D.5 specify the weekday and weekend diversity factors for the 2001 and 2004 typical (4^{th} floor) lighting electricity use. Figures D.20 to D.23 represent the 2001 and 2004 typical (4^{th} floor) receptacle electricity use for weekday and weekend day-types expressed as percentiles. Tables D.6 and D.7 specify the weekday and weekend diversity factors for the 2001 and 2004 typical (4^{th} floor) receptacle electricity use. Figures D.24 to D.35 represent the 2001 and 2004 conference center, senate print shop, and TLC print shop electricity use for weekday and weekend day-types expressed as percentiles. Table D.8 and D.13 specify the weekday and weekend diversity factors for the 2001 and 2004 conference center, senate print shop, and TLC print shop electricity use.

D.2.1. 2001 and 2004 Whole-building Lighting and Receptacle Electricity Use (WBE-MCC)

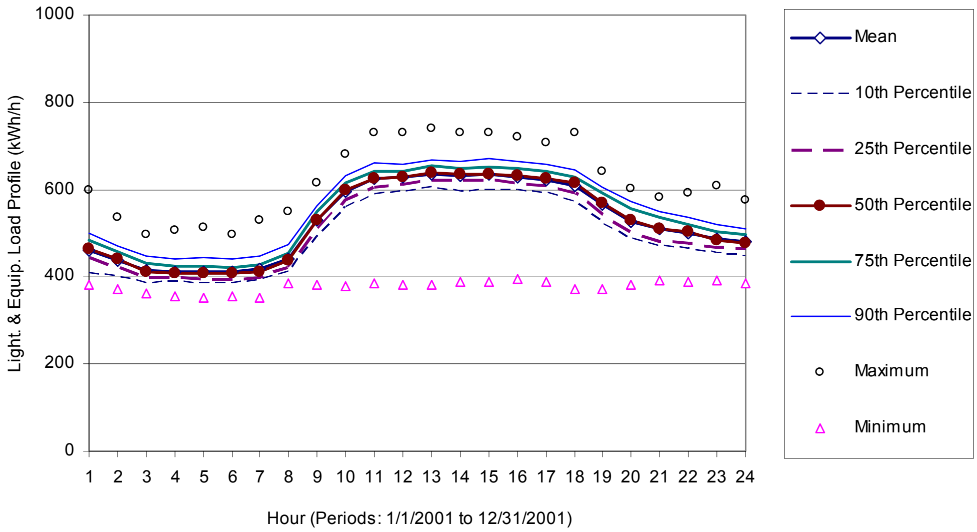


Figure D.12 *Weekday-type of the 2001whole-building lighting and receptacles loads. (Note: The dates that are excluded from the weekday profile are as follows: 1/1/01, 1/5/01, 1/8/01, 7/4/01, 11/15/01, 11/22/01, 11/23/01, 12/24/01, 12/25/01, and 12/26/01)*

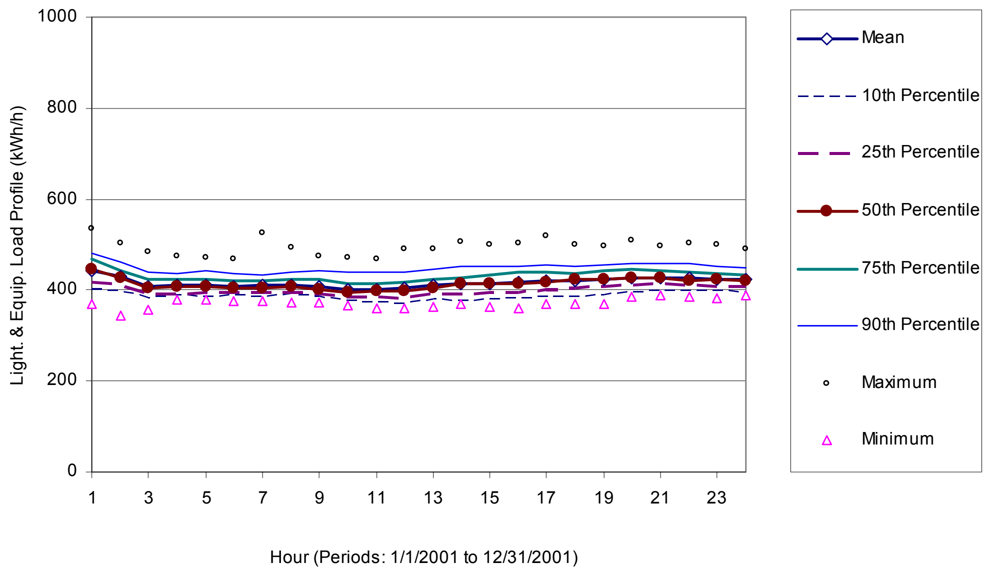


Figure D.13 *Weekend-type of the 2001 whole-building lighting and receptacles loads. (Note: The dates that are excluded from the weekday profile are as follows: 1/6/01, 1/7/01, 4/1/01 and 9/29/01)*

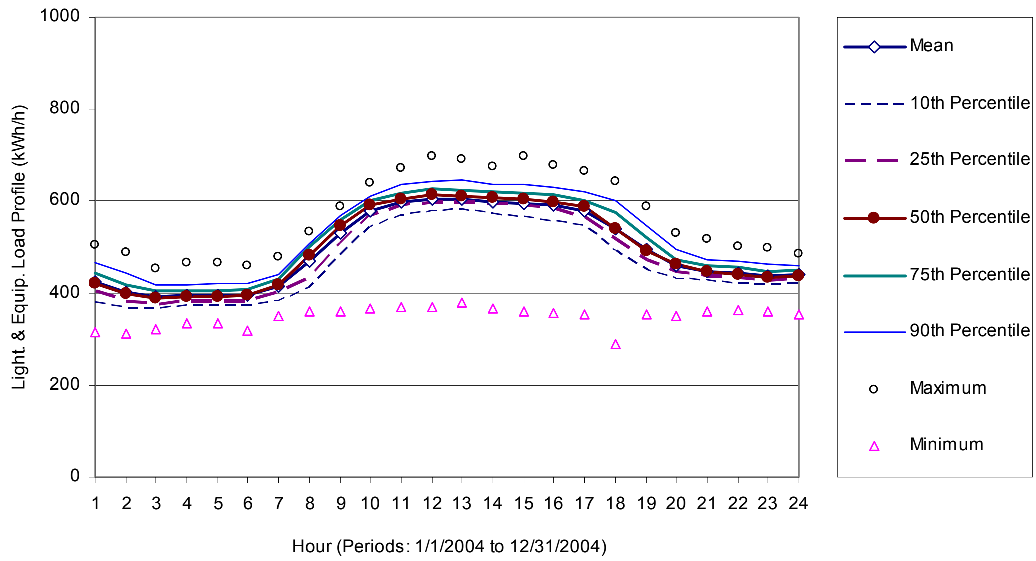


Figure D.14 *Weekday-type of the 2004 whole-building lighting and receptacle loads. (Note: The dates that are excluded from the weekday profile are as follows: 1/1/04, 12/31/04)*

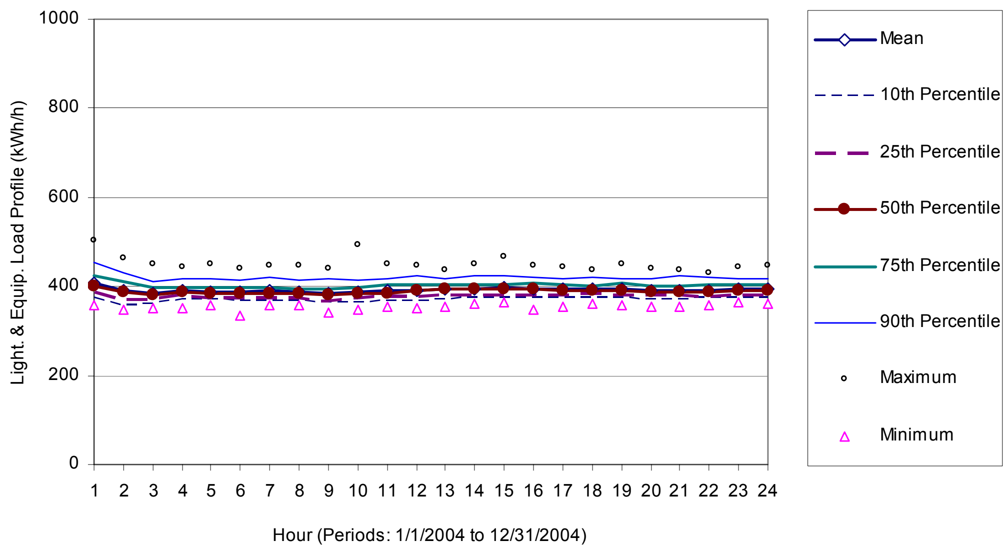


Figure D.15 *Weekend-type of 2004 whole-building lighting and receptacle loads. (Note: The dates that are excluded from the weekday profile are as follows: 7/25/04)*

Table D.2 2001 Whole-Building Lighting and Receptacle Load Profile (WBE-MCC)

WEEKDAYS: 2001 Weather Independent Loads (WBE-MCC)

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.67	0.71	0.63	0.61	0.65	0.68	0.70	0.72	0.83	0.58
2.00	0.64	0.68	0.61	0.60	0.63	0.65	0.66	0.68	0.75	0.58
3.00	0.62	0.65	0.59	0.58	0.60	0.62	0.64	0.65	0.70	0.56
4.00	0.61	0.64	0.59	0.59	0.60	0.61	0.63	0.65	0.71	0.56
5.00	0.61	0.64	0.59	0.58	0.60	0.61	0.63	0.65	0.72	0.56
6.00	0.61	0.64	0.59	0.59	0.60	0.61	0.62	0.64	0.70	0.56
7.00	0.62	0.64	0.59	0.59	0.60	0.62	0.63	0.65	0.74	0.56
8.00	0.65	0.68	0.62	0.62	0.63	0.65	0.67	0.69	0.76	0.59
9.00	0.75	0.79	0.72	0.72	0.74	0.75	0.78	0.79	0.83	0.58
10.00	0.84	0.87	0.80	0.80	0.82	0.84	0.86	0.87	0.92	0.58
11.00	0.87	0.91	0.83	0.83	0.85	0.87	0.89	0.91	0.98	0.58
12.00	0.87	0.91	0.83	0.84	0.86	0.87	0.89	0.91	0.97	0.58
13.00	0.88	0.92	0.84	0.84	0.87	0.88	0.89	0.92	1.00	0.58
14.00	0.87	0.91	0.83	0.83	0.86	0.87	0.89	0.91	0.97	0.59
15.00	0.88	0.92	0.84	0.84	0.87	0.88	0.90	0.92	0.98	0.59
16.00	0.87	0.91	0.83	0.84	0.86	0.88	0.89	0.91	0.97	0.59
17.00	0.86	0.91	0.82	0.83	0.85	0.87	0.88	0.91	0.95	0.59
18.00	0.84	0.89	0.80	0.80	0.83	0.85	0.87	0.88	0.96	0.57
19.00	0.79	0.84	0.75	0.74	0.77	0.80	0.82	0.84	0.88	0.57
20.00	0.75	0.80	0.71	0.71	0.72	0.75	0.79	0.81	0.84	0.58
21.00	0.73	0.77	0.69	0.69	0.70	0.73	0.76	0.78	0.82	0.59
22.00	0.72	0.76	0.68	0.68	0.69	0.72	0.74	0.77	0.81	0.59
23.00	0.71	0.74	0.67	0.67	0.68	0.70	0.73	0.75	0.82	0.59
24.00	0.69	0.79	0.59	0.66	0.67	0.69	0.71	0.73	0.79	-0.39
Daily Values	17.98	18.67	17.30	17.23	17.64	18.04	18.39	18.71	19.82	14.00
Daily Sum from Hourly	17.98	18.90	17.07	17.08	17.54	18.00	18.46	18.93	20.39	12.89

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

WEEKENDS: 2001 Weather Independent Loads (WBE-MCC)

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.65	0.69	0.61	0.60	0.62	0.65	0.68	0.70	0.74	0.57
2.00	0.63	0.66	0.60	0.60	0.61	0.63	0.65	0.67	0.71	0.54
3.00	0.61	0.63	0.59	0.58	0.59	0.61	0.63	0.64	0.68	0.56
4.00	0.61	0.63	0.59	0.59	0.59	0.61	0.63	0.64	0.67	0.57
5.00	0.61	0.63	0.59	0.58	0.60	0.61	0.62	0.64	0.67	0.57
6.00	0.61	0.63	0.59	0.58	0.59	0.61	0.62	0.64	0.67	0.57
7.00	0.61	0.63	0.59	0.59	0.59	0.61	0.62	0.64	0.73	0.57
8.00	0.61	0.64	0.59	0.59	0.60	0.61	0.63	0.64	0.69	0.57
9.00	0.61	0.63	0.58	0.58	0.59	0.60	0.63	0.64	0.67	0.57
10.00	0.60	0.63	0.57	0.57	0.58	0.59	0.61	0.63	0.68	0.56
11.00	0.60	0.63	0.57	0.57	0.58	0.59	0.61	0.64	0.69	0.55
12.00	0.60	0.63	0.57	0.57	0.58	0.60	0.62	0.64	0.72	0.55
13.00	0.61	0.64	0.58	0.57	0.59	0.60	0.62	0.65	0.72	0.55
14.00	0.61	0.64	0.58	0.58	0.59	0.61	0.63	0.66	0.74	0.56
15.00	0.61	0.64	0.58	0.58	0.59	0.61	0.63	0.65	0.73	0.55
16.00	0.62	0.65	0.58	0.57	0.59	0.61	0.64	0.65	0.74	0.55
17.00	0.62	0.65	0.59	0.58	0.60	0.61	0.64	0.66	0.73	0.56
18.00	0.62	0.65	0.59	0.58	0.60	0.62	0.64	0.66	0.73	0.56
19.00	0.62	0.65	0.59	0.59	0.61	0.62	0.64	0.66	0.73	0.56
20.00	0.63	0.66	0.60	0.59	0.61	0.63	0.65	0.66	0.73	0.58
21.00	0.63	0.65	0.60	0.60	0.61	0.63	0.64	0.66	0.73	0.58
22.00	0.63	0.65	0.60	0.60	0.61	0.62	0.64	0.66	0.73	0.58
23.00	0.63	0.65	0.60	0.60	0.61	0.62	0.64	0.65	0.71	0.58
24.00	0.62	0.65	0.60	0.59	0.61	0.62	0.64	0.65	0.71	0.59
Daily Values	14.79	15.37	14.21	14.12	14.39	14.73	15.16	15.61	16.65	13.63
Daily Sum from Hourly	14.79	15.45	14.12	14.01	14.33	14.71	15.18	15.63	17.04	13.54

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

Table D.3 2004 Whole-Building Lighting and Receptacle Loads Profile Table (WBE-MCC)

WEEKDAYS: 2004 Weather Independent Loads (WBE - MCC)

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.66	0.70	0.63	0.61	0.64	0.66	0.69	0.71	0.76	0.54
2.00	0.64	0.67	0.60	0.60	0.61	0.64	0.66	0.69	0.74	0.53
3.00	0.62	0.65	0.60	0.60	0.61	0.62	0.64	0.66	0.69	0.54
4.00	0.63	0.65	0.61	0.60	0.61	0.63	0.64	0.66	0.71	0.56
5.00	0.63	0.65	0.61	0.60	0.61	0.63	0.64	0.66	0.71	0.56
6.00	0.63	0.65	0.61	0.60	0.61	0.63	0.64	0.66	0.70	0.55
7.00	0.65	0.68	0.63	0.61	0.64	0.66	0.67	0.68	0.72	0.58
8.00	0.72	0.76	0.67	0.65	0.68	0.74	0.76	0.77	0.79	0.59
9.00	0.80	0.86	0.74	0.74	0.77	0.82	0.84	0.86	0.88	0.59
10.00	0.86	0.92	0.80	0.82	0.85	0.87	0.89	0.91	0.94	0.59
11.00	0.88	0.94	0.82	0.84	0.87	0.89	0.91	0.93	0.99	0.59
12.00	0.88	0.95	0.82	0.85	0.88	0.90	0.91	0.93	1.00	0.59
13.00	0.88	0.94	0.82	0.84	0.87	0.89	0.91	0.93	0.98	0.60
14.00	0.88	0.94	0.81	0.84	0.87	0.89	0.91	0.92	0.99	0.59
15.00	0.88	0.94	0.81	0.83	0.87	0.89	0.91	0.93	0.98	0.59
16.00	0.87	0.93	0.80	0.82	0.86	0.88	0.90	0.91	0.96	0.58
17.00	0.85	0.91	0.78	0.80	0.84	0.86	0.88	0.90	0.95	0.58
18.00	0.80	0.86	0.73	0.74	0.77	0.80	0.85	0.87	0.92	0.51
19.00	0.74	0.79	0.70	0.69	0.72	0.74	0.78	0.80	0.85	0.58
20.00	0.71	0.74	0.67	0.67	0.69	0.71	0.72	0.75	0.79	0.57
21.00	0.69	0.72	0.67	0.66	0.68	0.69	0.71	0.72	0.77	0.58
22.00	0.69	0.71	0.66	0.66	0.67	0.68	0.70	0.72	0.75	0.59
23.00	0.68	0.70	0.66	0.66	0.67	0.68	0.69	0.71	0.75	0.58
24.00	0.68	0.70	0.66	0.66	0.67	0.68	0.69	0.70	0.73	0.58
Daily Values	17.88	19.24	16.52	17.36	17.80	18.03	18.29	18.72	19.60	0.00
Daily Sum from Hourly	17.94	18.98	16.90	16.99	17.56	18.07	18.54	18.97	20.05	13.75

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

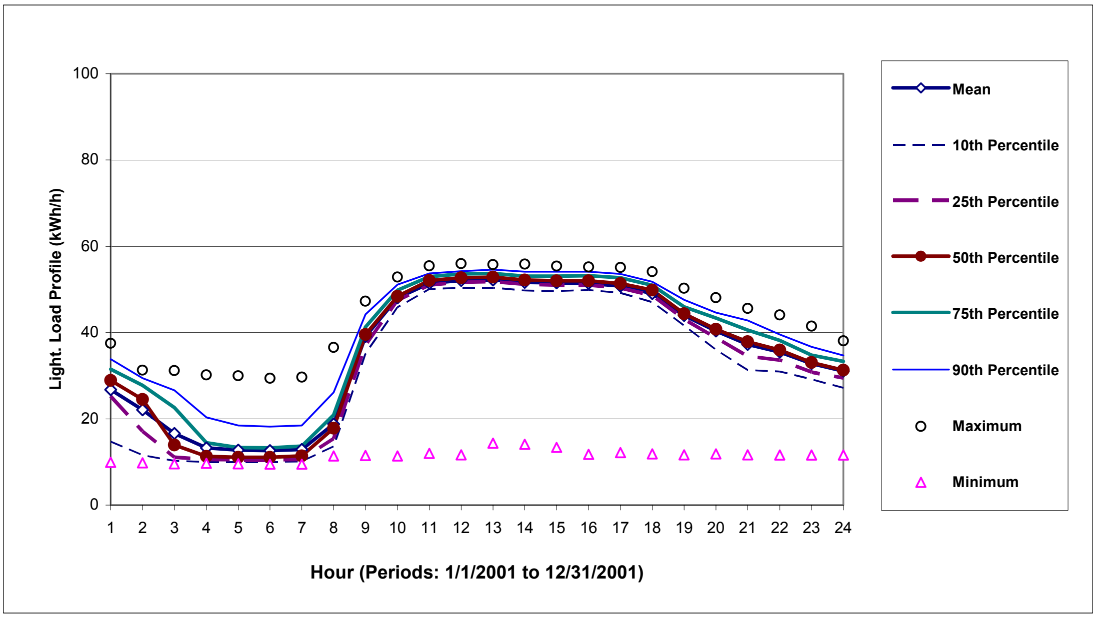
WEEKENDS: 2004 Weather Independent Loads (WBE - MCC)

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.64	0.68	0.61	0.60	0.62	0.64	0.67	0.70	0.75	0.58
2.00	0.62	0.66	0.59	0.58	0.60	0.62	0.65	0.67	0.70	0.57
3.00	0.62	0.64	0.59	0.59	0.60	0.61	0.63	0.65	0.69	0.58
4.00	0.62	0.64	0.60	0.60	0.61	0.62	0.63	0.65	0.69	0.58
5.00	0.62	0.64	0.60	0.60	0.60	0.61	0.63	0.65	0.69	0.59
6.00	0.62	0.64	0.60	0.59	0.60	0.61	0.63	0.65	0.68	0.56
7.00	0.62	0.64	0.60	0.60	0.60	0.61	0.63	0.66	0.69	0.58
8.00	0.62	0.64	0.59	0.59	0.60	0.61	0.63	0.65	0.69	0.58
9.00	0.61	0.64	0.59	0.59	0.60	0.61	0.63	0.65	0.68	0.57
10.00	0.62	0.64	0.59	0.59	0.60	0.61	0.63	0.65	0.73	0.57
11.00	0.62	0.64	0.60	0.59	0.60	0.61	0.64	0.65	0.69	0.58
12.00	0.62	0.65	0.60	0.60	0.61	0.62	0.64	0.66	0.69	0.58
13.00	0.62	0.64	0.60	0.60	0.61	0.62	0.64	0.65	0.68	0.58
14.00	0.63	0.65	0.60	0.60	0.61	0.62	0.64	0.66	0.69	0.59
15.00	0.63	0.65	0.60	0.60	0.61	0.62	0.64	0.66	0.71	0.59
16.00	0.63	0.65	0.60	0.60	0.61	0.62	0.64	0.66	0.68	0.57
17.00	0.62	0.64	0.60	0.60	0.61	0.62	0.63	0.65	0.68	0.58
18.00	0.62	0.64	0.60	0.60	0.61	0.62	0.63	0.65	0.68	0.59
19.00	0.62	0.65	0.60	0.60	0.61	0.62	0.64	0.65	0.69	0.58
20.00	0.62	0.64	0.60	0.60	0.61	0.62	0.63	0.66	0.68	0.58
21.00	0.62	0.64	0.60	0.60	0.61	0.62	0.63	0.66	0.68	0.58
22.00	0.62	0.64	0.60	0.60	0.61	0.62	0.64	0.66	0.67	0.59
23.00	0.62	0.65	0.60	0.60	0.61	0.62	0.64	0.65	0.69	0.59
24.00	0.62	0.64	0.60	0.60	0.61	0.62	0.64	0.65	0.69	0.59
Daily Values	14.94	15.42	14.47	14.46	14.57	14.86	15.14	15.63	16.45	14.14
Daily Sum from Hourly	14.94	15.49	14.39	14.32	14.54	14.85	15.25	15.75	16.58	13.92

Daily Values: The Daily results as the statistics are applied on daily data.

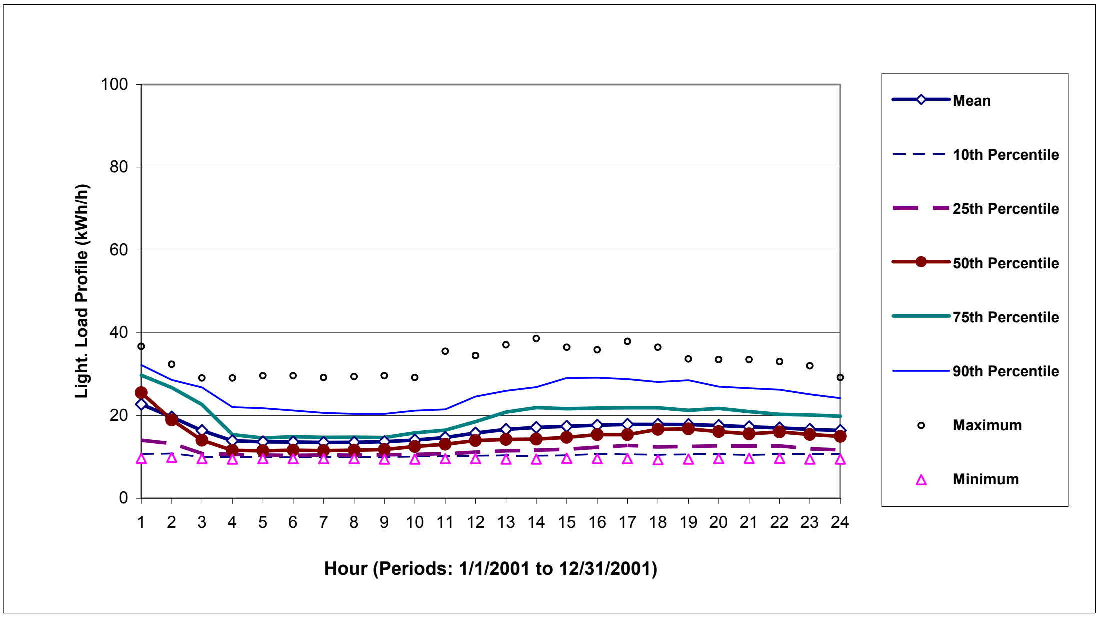
Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

D.2.2. 2001 and 2004 Typical (4th Floor) Lighting Electricity Use



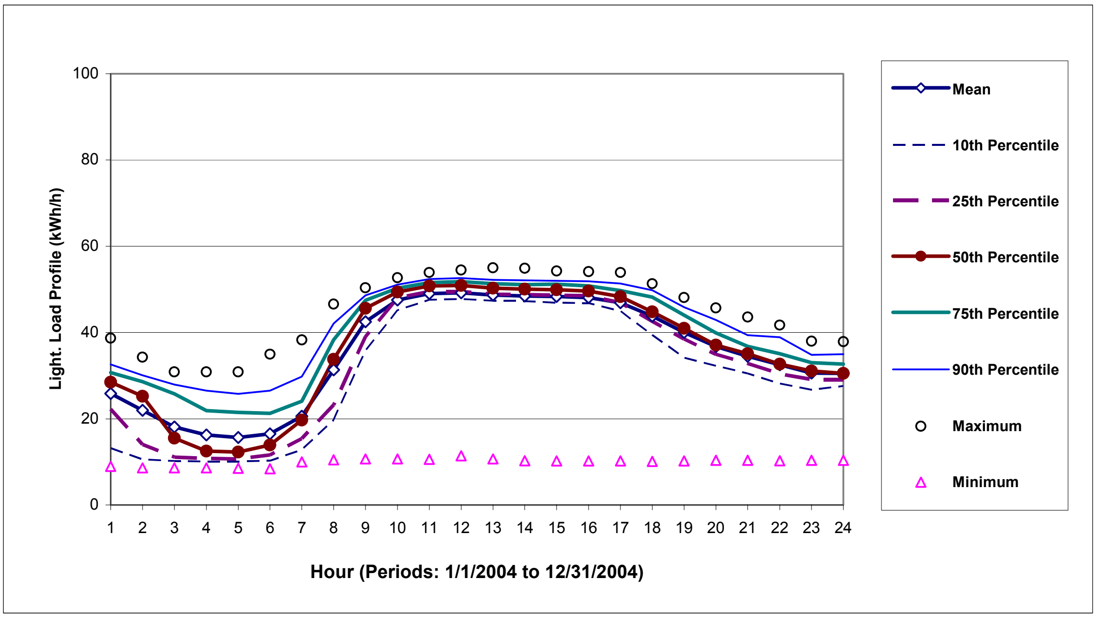
The dates that are excluded from the weekday profile are as follows:
1/1/01, 7/4/01, 11/22/01, 11/23/01, 12/24/01, 12/25/01, and 12/26/01

Figure D.16 *Weekday-types of the 2001 typical (4th Floor) lighting electricity use.*



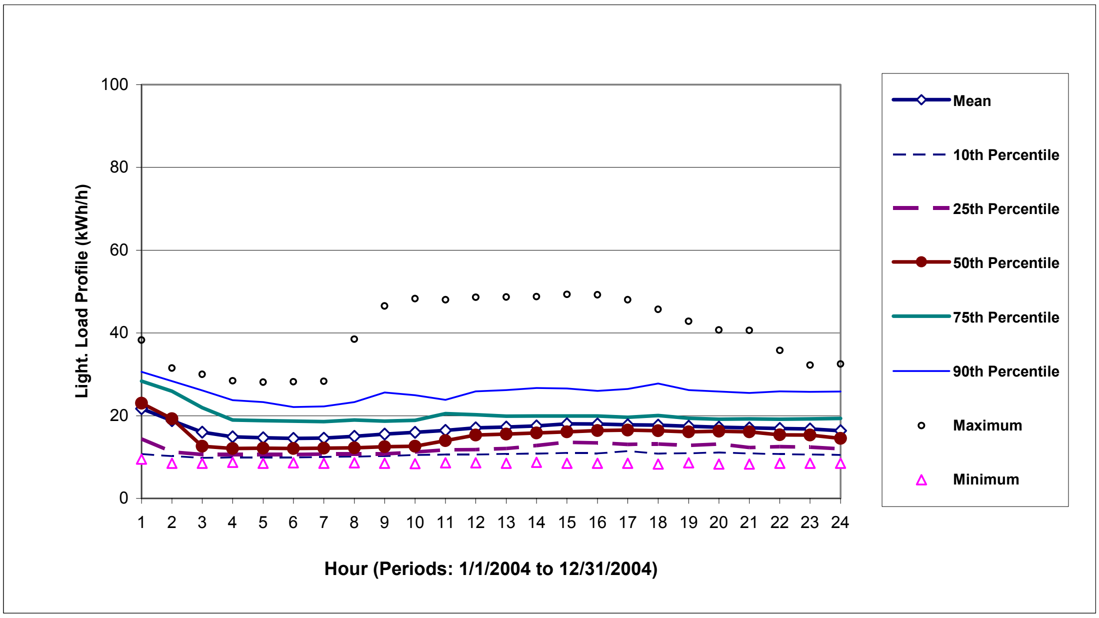
The dates that are excluded from the weekday profile are as follows:
4/1/01 and 9/29/01

Figure D.17 *Weekend-types of the 2001 typical (4th Floor) lighting electricity use.*



The dates that are excluded from the weekday profile are as follow: 8/09/04

Figure D.18 *Weekday-type of the 2004 typical (4th Floor) lighting electricity use.*



The dates that are excluded from the weekday profile are as follows: 2/29/04 and 7/25/04

Figure D.19 *Weekend-type of the 2004 typical (4th Floor) lighting electricity use.*

Table D.4 2001 Typical (4th floor) Lighting Electricity Use Profile Table

WEEKDAYS: 2001 4th Floor Lights

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.48	0.60	0.35	0.26	0.45	0.52	0.56	0.60	0.67	0.18
2.00	0.39	0.51	0.28	0.21	0.31	0.44	0.50	0.53	0.56	0.18
3.00	0.30	0.41	0.18	0.18	0.20	0.25	0.40	0.48	0.56	0.17
4.00	0.24	0.32	0.16	0.18	0.19	0.20	0.26	0.36	0.54	0.17
5.00	0.23	0.30	0.16	0.18	0.19	0.20	0.24	0.33	0.54	0.17
6.00	0.23	0.29	0.16	0.18	0.19	0.20	0.24	0.33	0.53	0.17
7.00	0.23	0.30	0.16	0.18	0.19	0.20	0.24	0.33	0.53	0.17
8.00	0.34	0.42	0.25	0.24	0.28	0.32	0.37	0.47	0.65	0.20
9.00	0.70	0.78	0.62	0.63	0.66	0.71	0.74	0.79	0.84	0.21
10.00	0.86	0.93	0.78	0.82	0.85	0.86	0.89	0.91	0.94	0.20
11.00	0.92	0.99	0.84	0.89	0.91	0.93	0.95	0.96	0.99	0.21
12.00	0.93	1.00	0.86	0.90	0.92	0.94	0.96	0.97	1.00	0.21
13.00	0.93	1.00	0.87	0.90	0.93	0.94	0.96	0.98	1.00	0.26
14.00	0.92	0.99	0.85	0.89	0.91	0.93	0.95	0.97	1.00	0.25
15.00	0.92	0.99	0.85	0.89	0.91	0.93	0.95	0.97	0.99	0.24
16.00	0.92	0.99	0.85	0.89	0.91	0.93	0.95	0.97	0.99	0.21
17.00	0.91	0.98	0.83	0.88	0.90	0.92	0.94	0.96	0.98	0.22
18.00	0.88	0.95	0.80	0.84	0.87	0.89	0.91	0.93	0.97	0.21
19.00	0.78	0.86	0.71	0.74	0.77	0.79	0.82	0.85	0.90	0.21
20.00	0.72	0.80	0.64	0.64	0.69	0.73	0.78	0.80	0.86	0.21
21.00	0.67	0.75	0.58	0.56	0.62	0.68	0.72	0.76	0.81	0.21
22.00	0.63	0.70	0.57	0.55	0.60	0.64	0.68	0.71	0.79	0.21
23.00	0.59	0.65	0.52	0.52	0.55	0.59	0.62	0.66	0.74	0.21
24.00	0.56	0.61	0.50	0.49	0.53	0.56	0.59	0.62	0.68	0.21
Daily Values	15.25	16.46	14.04	14.48	14.88	15.28	15.76	16.43	17.79	5.16
Daily Sum from Hourly	15.25	17.12	13.38	13.64	14.51	15.29	16.22	17.20	19.05	4.88

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

WEEKENDS: 2001 4th Floor Lights

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.41	0.55	0.26	0.19	0.25	0.46	0.53	0.58	0.66	0.17
2.00	0.35	0.47	0.23	0.19	0.24	0.34	0.48	0.51	0.58	0.18
3.00	0.29	0.41	0.17	0.18	0.19	0.25	0.40	0.48	0.52	0.17
4.00	0.25	0.34	0.16	0.18	0.19	0.21	0.27	0.39	0.52	0.17
5.00	0.24	0.33	0.16	0.18	0.19	0.21	0.26	0.39	0.53	0.17
6.00	0.24	0.33	0.16	0.18	0.19	0.21	0.27	0.38	0.53	0.17
7.00	0.24	0.32	0.16	0.18	0.19	0.21	0.26	0.37	0.52	0.17
8.00	0.24	0.32	0.16	0.18	0.19	0.21	0.26	0.36	0.53	0.17
9.00	0.24	0.33	0.16	0.18	0.19	0.21	0.26	0.36	0.53	0.17
10.00	0.25	0.34	0.16	0.18	0.19	0.22	0.28	0.38	0.52	0.17
11.00	0.26	0.36	0.17	0.18	0.19	0.23	0.29	0.38	0.63	0.17
12.00	0.28	0.38	0.18	0.18	0.20	0.25	0.33	0.44	0.62	0.17
13.00	0.30	0.41	0.18	0.19	0.21	0.25	0.37	0.46	0.66	0.17
14.00	0.31	0.43	0.18	0.18	0.21	0.26	0.39	0.48	0.69	0.17
15.00	0.31	0.43	0.19	0.19	0.21	0.26	0.39	0.52	0.65	0.17
16.00	0.31	0.44	0.19	0.19	0.22	0.28	0.39	0.52	0.64	0.17
17.00	0.32	0.44	0.20	0.19	0.23	0.27	0.39	0.51	0.68	0.17
18.00	0.32	0.44	0.20	0.19	0.22	0.30	0.39	0.50	0.65	0.17
19.00	0.32	0.44	0.20	0.19	0.22	0.30	0.38	0.51	0.60	0.17
20.00	0.31	0.43	0.20	0.19	0.23	0.29	0.39	0.48	0.60	0.17
21.00	0.31	0.42	0.20	0.19	0.23	0.28	0.37	0.47	0.60	0.17
22.00	0.30	0.41	0.20	0.19	0.23	0.29	0.36	0.47	0.59	0.17
23.00	0.30	0.40	0.20	0.19	0.21	0.28	0.36	0.45	0.57	0.17
24.00	0.29	0.39	0.20	0.19	0.21	0.27	0.35	0.43	0.52	0.17
Daily Values	7.01	9.12	4.89	5.03	5.52	6.28	8.16	10.51	12.51	4.29
Daily Sum from Hourly	7.01	9.54	4.47	4.43	5.00	6.31	8.45	10.84	14.13	4.11

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

Table D.5 2004 Typical (4th floor) Lighting Electricity Use Profile

WEEKDAYS: 2004 4th Floor Lights

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.47	0.60	0.34	0.24	0.40	0.52	0.56	0.59	0.70	0.16
2.00	0.40	0.54	0.26	0.19	0.25	0.46	0.52	0.55	0.62	0.16
3.00	0.33	0.46	0.19	0.19	0.20	0.28	0.47	0.51	0.56	0.16
4.00	0.29	0.41	0.18	0.18	0.20	0.23	0.40	0.48	0.56	0.16
5.00	0.28	0.40	0.17	0.18	0.19	0.22	0.39	0.47	0.56	0.15
6.00	0.30	0.41	0.19	0.19	0.21	0.25	0.39	0.48	0.64	0.15
7.00	0.37	0.49	0.26	0.23	0.28	0.36	0.44	0.54	0.70	0.18
8.00	0.57	0.73	0.41	0.36	0.42	0.61	0.70	0.77	0.85	0.19
9.00	0.77	0.91	0.63	0.65	0.71	0.83	0.86	0.88	0.92	0.19
10.00	0.86	0.99	0.73	0.82	0.87	0.90	0.91	0.93	0.96	0.19
11.00	0.89	1.02	0.76	0.87	0.90	0.92	0.94	0.95	0.98	0.19
12.00	0.89	1.02	0.77	0.87	0.90	0.93	0.94	0.96	0.99	0.21
13.00	0.89	1.01	0.76	0.86	0.89	0.91	0.93	0.95	1.00	0.19
14.00	0.88	1.01	0.75	0.86	0.89	0.91	0.93	0.95	1.00	0.19
15.00	0.88	1.01	0.75	0.85	0.89	0.91	0.93	0.95	0.99	0.19
16.00	0.87	1.00	0.75	0.85	0.88	0.90	0.92	0.94	0.98	0.19
17.00	0.85	0.98	0.72	0.82	0.85	0.88	0.90	0.93	0.98	0.19
18.00	0.80	0.93	0.67	0.72	0.77	0.81	0.88	0.91	0.93	0.18
19.00	0.73	0.84	0.61	0.62	0.70	0.75	0.80	0.83	0.87	0.19
20.00	0.67	0.77	0.57	0.59	0.63	0.67	0.73	0.78	0.83	0.19
21.00	0.63	0.72	0.54	0.55	0.60	0.64	0.67	0.72	0.79	0.19
22.00	0.59	0.68	0.50	0.51	0.55	0.59	0.64	0.71	0.76	0.19
23.00	0.56	0.63	0.48	0.49	0.53	0.57	0.60	0.63	0.69	0.19
24.00	0.55	0.63	0.48	0.50	0.53	0.55	0.59	0.64	0.69	0.19
Daily Values	15.34	17.40	13.29	14.33	14.85	15.50	16.41	17.10	18.15	4.83
Daily Sum from Hourly	15.34	18.22	12.46	13.19	14.26	15.61	17.04	18.04	19.56	4.35

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

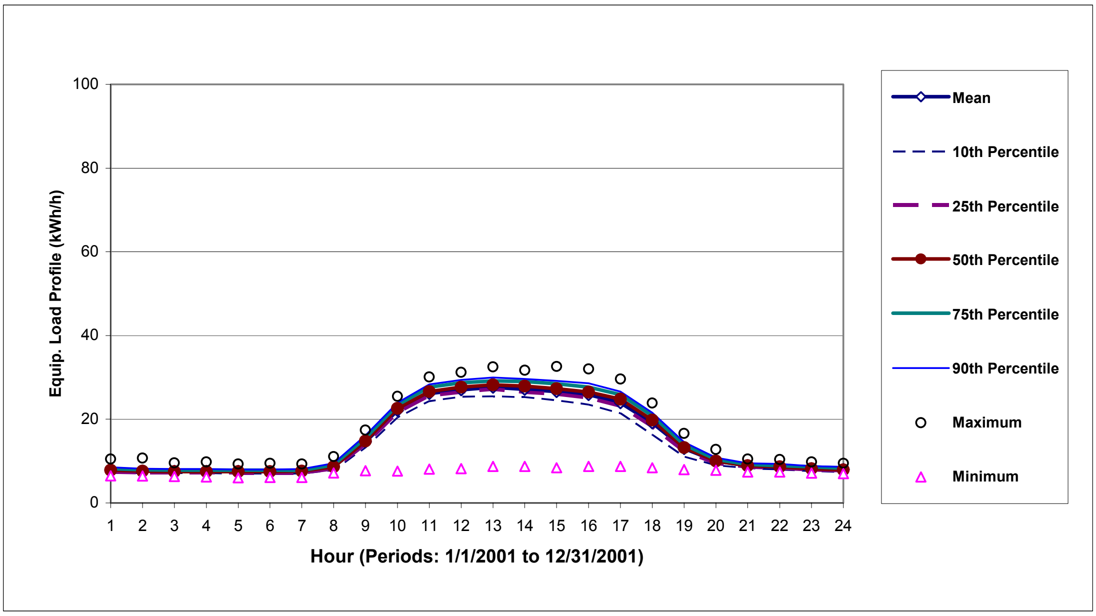
WEEKENDS: 2001 4th Floor Lights

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.40	0.54	0.25	0.19	0.26	0.42	0.52	0.56	0.70	0.17
2.00	0.34	0.47	0.21	0.19	0.20	0.35	0.47	0.52	0.57	0.15
3.00	0.29	0.41	0.18	0.18	0.19	0.23	0.40	0.47	0.55	0.15
4.00	0.27	0.37	0.17	0.18	0.19	0.22	0.34	0.43	0.52	0.16
5.00	0.27	0.36	0.17	0.18	0.19	0.22	0.34	0.42	0.51	0.15
6.00	0.26	0.36	0.17	0.18	0.19	0.22	0.34	0.40	0.51	0.16
7.00	0.26	0.36	0.17	0.18	0.19	0.22	0.34	0.40	0.51	0.15
8.00	0.27	0.38	0.17	0.18	0.19	0.22	0.34	0.42	0.70	0.16
9.00	0.28	0.41	0.16	0.19	0.20	0.23	0.34	0.47	0.85	0.15
10.00	0.29	0.42	0.16	0.19	0.20	0.23	0.34	0.45	0.88	0.15
11.00	0.30	0.43	0.17	0.19	0.21	0.25	0.37	0.43	0.87	0.16
12.00	0.31	0.44	0.18	0.19	0.21	0.28	0.37	0.47	0.88	0.16
13.00	0.31	0.44	0.18	0.20	0.22	0.28	0.36	0.48	0.89	0.15
14.00	0.32	0.45	0.19	0.20	0.23	0.29	0.36	0.49	0.89	0.16
15.00	0.33	0.46	0.20	0.20	0.25	0.29	0.36	0.48	0.90	0.15
16.00	0.33	0.45	0.20	0.20	0.24	0.30	0.36	0.47	0.89	0.15
17.00	0.32	0.45	0.20	0.21	0.24	0.30	0.36	0.48	0.87	0.15
18.00	0.32	0.45	0.20	0.20	0.24	0.30	0.36	0.51	0.83	0.15
19.00	0.32	0.44	0.20	0.20	0.23	0.29	0.35	0.48	0.78	0.16
20.00	0.31	0.43	0.20	0.20	0.24	0.30	0.35	0.47	0.74	0.15
21.00	0.31	0.42	0.20	0.20	0.22	0.29	0.35	0.46	0.74	0.15
22.00	0.31	0.41	0.20	0.19	0.23	0.28	0.35	0.47	0.65	0.15
23.00	0.31	0.41	0.20	0.19	0.23	0.28	0.35	0.47	0.59	0.15
24.00	0.30	0.40	0.19	0.19	0.22	0.26	0.35	0.47	0.59	0.15
Daily Values	7.33	9.71	4.96	4.93	5.55	6.43	9.00	10.54	15.76	3.84
Daily Sum from Hourly	7.33	10.13	4.54	4.60	5.24	6.55	8.79	11.18	17.40	3.73

Daily Values: The Daily results as the statistics are applied on daily data.

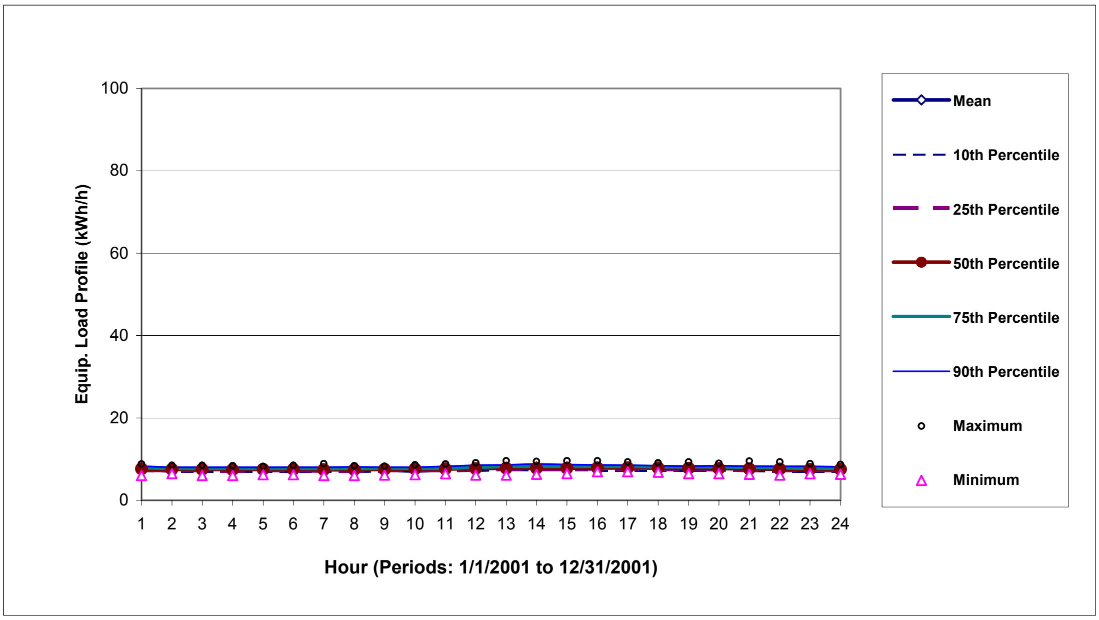
Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

D.2.3. 2001 and 2004 Typical (4th Floor) Receptacles Electricity Use



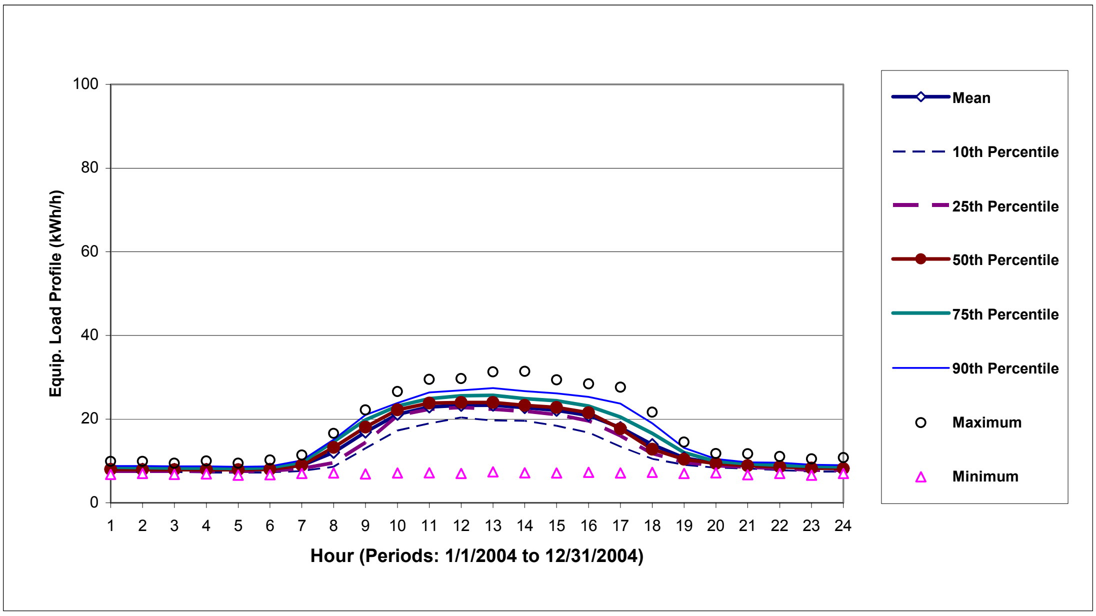
The dates that are excluded from the weekday profile are as follows:
1/1/01, 7/4/01, 11/22/01, 11/23/01, 12/24/01, 12/25/01, and 12/26/01

Figure D.20 *Weekday-type of the 2001 typical (4th Floor) receptacles electricity use.*



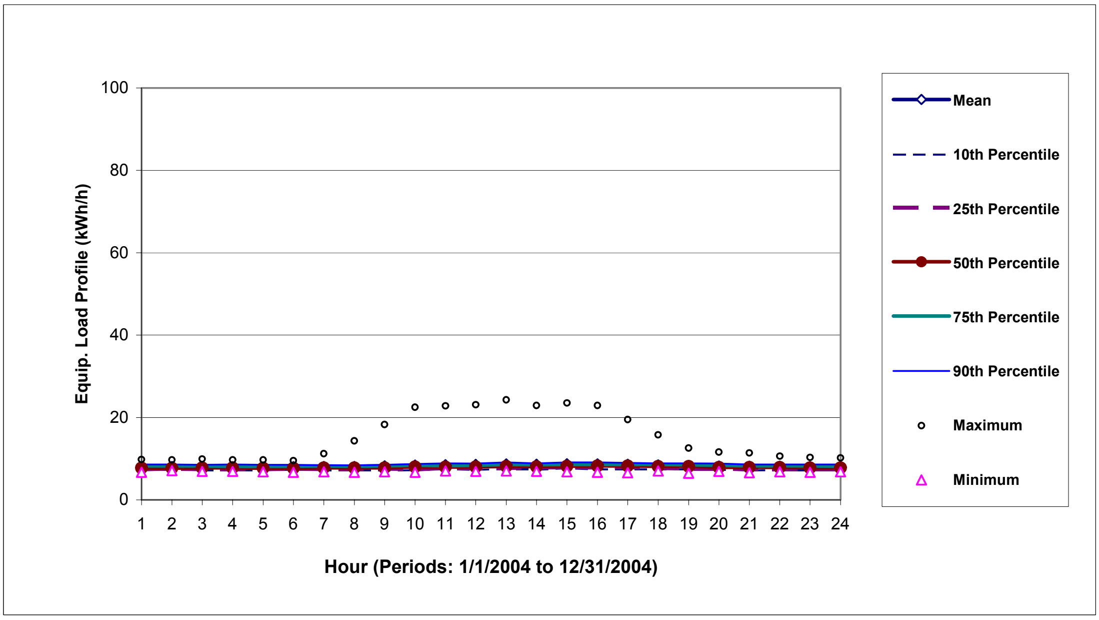
The dates that are excluded from the weekday profile are as follows:
4/1/01 and 9/29/01

Figure D.21 *Weekend-type of the 2001 typical (4th Floor) receptacles electricity use.*



The dates that are excluded from the weekday profile are as follow: 8/9/04

Figure D.22 *Weekday-type of the 2004 typical (4th Floor) receptacles electricity use.*



The dates that are excluded from the weekday profile are as follow: 2/29/04 and 7/25/04

Figure D.23 *Weekend-type of the 2004 typical (4th Floor) receptacles electricity use.*

Table D.6 2001 Typical (4th Floor) Receptacles Electricity Use Profile

WEEKDAYS: 2001 4th Floor Receptacles

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.24	0.26	0.22	0.22	0.23	0.24	0.25	0.26	0.32	0.20
2.00	0.23	0.25	0.22	0.22	0.22	0.23	0.24	0.25	0.33	0.20
3.00	0.23	0.25	0.22	0.22	0.22	0.23	0.24	0.25	0.29	0.19
4.00	0.23	0.24	0.22	0.22	0.22	0.23	0.24	0.25	0.30	0.19
5.00	0.23	0.24	0.22	0.21	0.22	0.23	0.24	0.25	0.29	0.18
6.00	0.23	0.24	0.22	0.21	0.22	0.23	0.24	0.25	0.29	0.19
7.00	0.23	0.24	0.22	0.21	0.22	0.23	0.24	0.25	0.29	0.19
8.00	0.27	0.28	0.25	0.24	0.25	0.26	0.28	0.29	0.34	0.22
9.00	0.45	0.49	0.40	0.40	0.43	0.45	0.48	0.49	0.53	0.24
10.00	0.68	0.75	0.60	0.63	0.66	0.69	0.72	0.73	0.78	0.23
11.00	0.80	0.89	0.71	0.75	0.79	0.82	0.85	0.87	0.92	0.25
12.00	0.83	0.93	0.73	0.78	0.81	0.85	0.88	0.90	0.96	0.25
13.00	0.85	0.95	0.75	0.78	0.83	0.87	0.90	0.92	1.00	0.27
14.00	0.83	0.94	0.73	0.78	0.81	0.86	0.89	0.91	0.97	0.27
15.00	0.82	0.92	0.71	0.75	0.80	0.84	0.87	0.90	1.00	0.26
16.00	0.79	0.90	0.68	0.72	0.77	0.81	0.85	0.88	0.98	0.27
17.00	0.73	0.84	0.63	0.66	0.71	0.76	0.79	0.82	0.91	0.27
18.00	0.59	0.67	0.50	0.50	0.56	0.61	0.64	0.66	0.73	0.26
19.00	0.40	0.44	0.35	0.34	0.38	0.40	0.43	0.45	0.51	0.25
20.00	0.31	0.33	0.28	0.28	0.29	0.31	0.32	0.33	0.39	0.24
21.00	0.27	0.29	0.26	0.25	0.26	0.27	0.28	0.29	0.32	0.23
22.00	0.26	0.28	0.25	0.25	0.25	0.26	0.27	0.29	0.32	0.23
23.00	0.25	0.27	0.24	0.23	0.24	0.25	0.26	0.27	0.30	0.22
24.00	0.24	0.26	0.23	0.23	0.24	0.24	0.25	0.26	0.29	0.21
Daily Values	11.00	11.95	10.04	10.35	10.79	11.20	11.50	11.74	12.45	5.87
Daily Sum from Hourly	11.00	12.16	9.83	10.07	10.65	11.18	11.65	12.00	13.37	5.48

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

WEEKENDS: 2001 4th Floor Receptacles

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.23	0.25	0.22	0.21	0.22	0.23	0.24	0.25	0.27	0.18
2.00	0.23	0.24	0.22	0.21	0.22	0.23	0.24	0.25	0.26	0.20
3.00	0.23	0.24	0.22	0.21	0.22	0.23	0.24	0.25	0.26	0.18
4.00	0.23	0.24	0.22	0.21	0.22	0.23	0.24	0.25	0.26	0.18
5.00	0.23	0.24	0.22	0.21	0.22	0.23	0.24	0.25	0.25	0.19
6.00	0.23	0.24	0.21	0.21	0.22	0.23	0.24	0.25	0.26	0.19
7.00	0.23	0.24	0.21	0.21	0.22	0.23	0.24	0.25	0.27	0.18
8.00	0.23	0.24	0.21	0.21	0.22	0.23	0.24	0.25	0.26	0.18
9.00	0.23	0.24	0.22	0.21	0.22	0.23	0.24	0.25	0.25	0.19
10.00	0.23	0.24	0.22	0.21	0.22	0.23	0.24	0.25	0.26	0.19
11.00	0.23	0.25	0.22	0.22	0.22	0.23	0.24	0.25	0.27	0.20
12.00	0.24	0.25	0.22	0.22	0.23	0.24	0.25	0.26	0.28	0.19
13.00	0.24	0.26	0.22	0.22	0.23	0.24	0.25	0.26	0.29	0.19
14.00	0.24	0.26	0.22	0.22	0.23	0.24	0.25	0.27	0.29	0.19
15.00	0.24	0.26	0.22	0.22	0.23	0.24	0.25	0.27	0.29	0.20
16.00	0.24	0.26	0.23	0.22	0.23	0.24	0.25	0.26	0.29	0.21
17.00	0.24	0.26	0.23	0.22	0.23	0.24	0.25	0.26	0.29	0.21
18.00	0.24	0.25	0.23	0.22	0.23	0.24	0.25	0.26	0.28	0.21
19.00	0.24	0.25	0.22	0.22	0.23	0.24	0.25	0.25	0.29	0.20
20.00	0.24	0.25	0.22	0.22	0.23	0.24	0.25	0.26	0.28	0.20
21.00	0.23	0.25	0.22	0.21	0.22	0.23	0.24	0.25	0.29	0.19
22.00	0.23	0.25	0.22	0.21	0.22	0.23	0.24	0.25	0.29	0.19
23.00	0.23	0.25	0.22	0.21	0.22	0.23	0.24	0.25	0.27	0.20
24.00	0.23	0.25	0.21	0.21	0.22	0.23	0.24	0.25	0.27	0.19
Daily Values	5.62	5.91	5.33	5.24	5.43	5.66	5.78	5.94	6.33	4.68
Daily Sum from Hourly	5.62	5.98	5.25	5.18	5.39	5.61	5.84	6.08	6.57	4.64

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

Table D.7 2004 Typical (4th Floor) Receptacle Electricity Use Profile

WEEKDAYS: 2004 4th Floor Receptacles

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.26	0.28	0.24	0.24	0.24	0.25	0.27	0.28	0.32	0.22
2.00	0.26	0.27	0.24	0.24	0.24	0.25	0.27	0.28	0.32	0.22
3.00	0.25	0.27	0.24	0.24	0.24	0.25	0.26	0.28	0.30	0.22
4.00	0.25	0.27	0.24	0.23	0.24	0.25	0.26	0.28	0.32	0.22
5.00	0.25	0.27	0.24	0.23	0.24	0.25	0.26	0.27	0.30	0.21
6.00	0.26	0.27	0.24	0.23	0.24	0.25	0.27	0.28	0.32	0.21
7.00	0.28	0.32	0.25	0.24	0.26	0.29	0.31	0.32	0.36	0.22
8.00	0.38	0.47	0.30	0.27	0.31	0.42	0.46	0.48	0.53	0.23
9.00	0.54	0.65	0.43	0.41	0.46	0.58	0.63	0.67	0.71	0.22
10.00	0.67	0.79	0.55	0.55	0.67	0.71	0.74	0.76	0.85	0.23
11.00	0.73	0.86	0.60	0.61	0.71	0.76	0.79	0.84	0.94	0.23
12.00	0.74	0.88	0.61	0.65	0.73	0.76	0.82	0.86	0.95	0.22
13.00	0.74	0.88	0.60	0.63	0.71	0.76	0.82	0.87	1.00	0.24
14.00	0.72	0.86	0.59	0.62	0.70	0.74	0.79	0.85	1.00	0.23
15.00	0.70	0.84	0.57	0.59	0.67	0.73	0.78	0.83	0.94	0.23
16.00	0.66	0.79	0.54	0.54	0.62	0.68	0.74	0.81	0.90	0.23
17.00	0.57	0.70	0.44	0.43	0.51	0.56	0.65	0.75	0.88	0.23
18.00	0.44	0.55	0.34	0.33	0.38	0.41	0.53	0.61	0.69	0.23
19.00	0.34	0.39	0.29	0.29	0.31	0.33	0.38	0.42	0.46	0.22
20.00	0.30	0.33	0.27	0.27	0.28	0.30	0.32	0.33	0.38	0.23
21.00	0.28	0.31	0.26	0.26	0.27	0.28	0.30	0.31	0.37	0.21
22.00	0.28	0.30	0.25	0.25	0.26	0.27	0.29	0.31	0.35	0.22
23.00	0.26	0.28	0.24	0.24	0.25	0.26	0.28	0.29	0.33	0.21
24.00	0.26	0.28	0.24	0.24	0.25	0.26	0.27	0.29	0.34	0.22
Daily Values	10.46	11.78	9.14	9.42	10.14	10.63	11.23	11.74	12.88	5.51
Daily Sum from Hourly	10.46	12.12	8.81	8.82	9.80	10.63	11.48	12.26	13.86	5.35

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

WEEKENDS: 2004 4th Floor Receptacles

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.25	0.27	0.23	0.23	0.24	0.25	0.26	0.27	0.31	0.21
2.00	0.25	0.27	0.23	0.23	0.24	0.25	0.26	0.27	0.31	0.23
3.00	0.25	0.27	0.23	0.23	0.24	0.25	0.26	0.27	0.32	0.22
4.00	0.25	0.27	0.23	0.23	0.24	0.25	0.26	0.27	0.31	0.22
5.00	0.25	0.27	0.23	0.23	0.24	0.25	0.26	0.27	0.31	0.22
6.00	0.25	0.27	0.23	0.23	0.24	0.25	0.26	0.27	0.30	0.21
7.00	0.25	0.27	0.23	0.23	0.24	0.25	0.26	0.27	0.36	0.22
8.00	0.25	0.28	0.22	0.23	0.24	0.25	0.26	0.27	0.46	0.21
9.00	0.26	0.31	0.21	0.23	0.24	0.25	0.26	0.27	0.58	0.22
10.00	0.26	0.33	0.20	0.23	0.24	0.25	0.27	0.28	0.72	0.21
11.00	0.26	0.33	0.20	0.24	0.24	0.25	0.26	0.28	0.73	0.22
12.00	0.27	0.34	0.20	0.23	0.24	0.25	0.27	0.28	0.74	0.22
13.00	0.27	0.34	0.20	0.24	0.25	0.26	0.27	0.29	0.77	0.22
14.00	0.27	0.34	0.20	0.23	0.25	0.26	0.27	0.28	0.73	0.22
15.00	0.27	0.34	0.20	0.24	0.25	0.26	0.27	0.29	0.75	0.22
16.00	0.27	0.34	0.20	0.24	0.25	0.26	0.27	0.29	0.73	0.21
17.00	0.27	0.32	0.22	0.24	0.25	0.26	0.27	0.29	0.62	0.21
18.00	0.26	0.30	0.23	0.24	0.25	0.26	0.27	0.28	0.50	0.22
19.00	0.26	0.29	0.23	0.24	0.24	0.26	0.27	0.28	0.40	0.21
20.00	0.26	0.28	0.23	0.23	0.24	0.25	0.27	0.28	0.37	0.22
21.00	0.25	0.28	0.23	0.23	0.24	0.25	0.26	0.27	0.36	0.21
22.00	0.25	0.27	0.23	0.23	0.24	0.25	0.26	0.27	0.34	0.22
23.00	0.25	0.27	0.23	0.23	0.24	0.25	0.26	0.27	0.33	0.21
24.00	0.25	0.27	0.23	0.23	0.24	0.25	0.26	0.27	0.32	0.22
Daily Values	6.19	7.01	5.37	5.66	5.82	6.01	6.30	6.64	11.56	5.34
Daily Sum from Hourly	6.19	7.10	5.27	5.56	5.76	6.05	6.37	6.66	11.66	5.20

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

D.2.4. 2001 and 2004 Independent Electricity Use

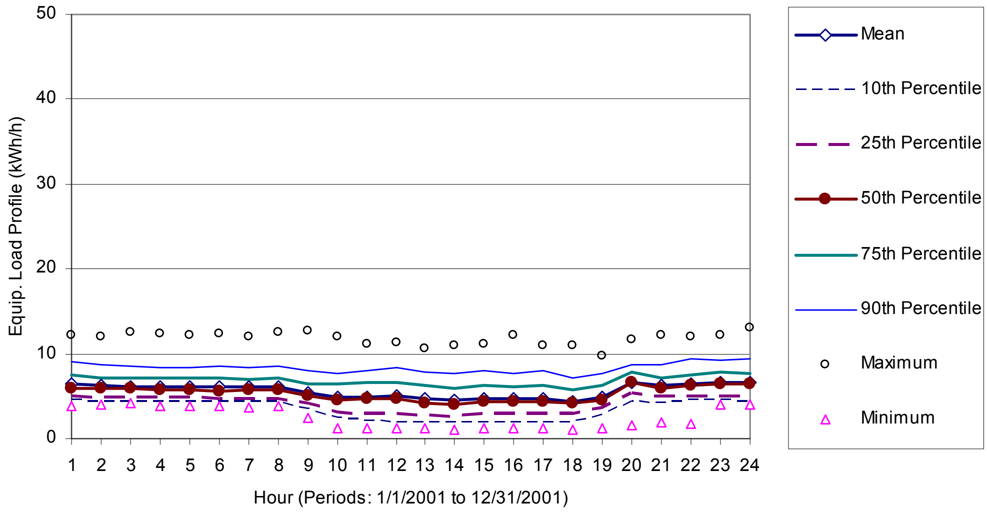


Figure D.24 *Weekday-type of the 2001 conference center electricity use.*
(Note: The dates that are excluded from the weekday profile are as follows: 2/29/01).

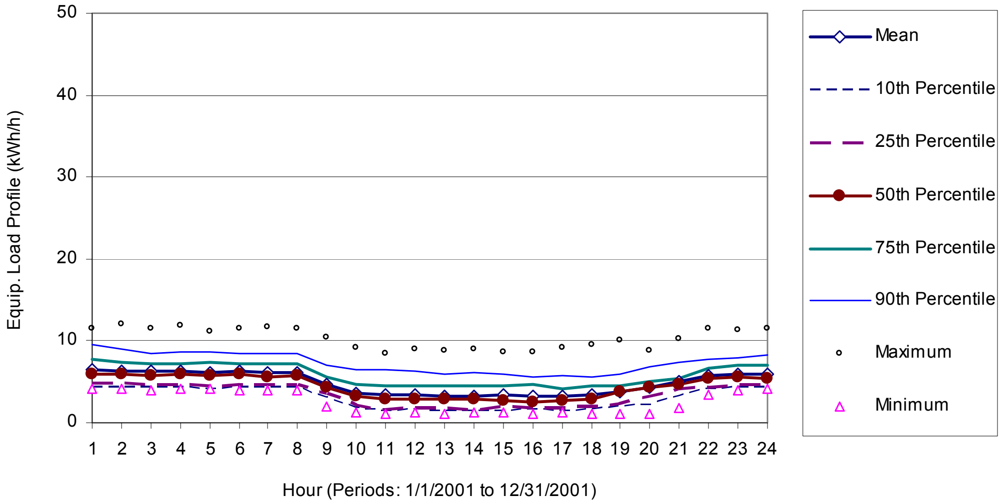


Figure D.25 *Weekend-type of the 2001 conference center electricity use.*
(Note: The dates that are excluded from the weekday profile are as follows: 2/29/01).

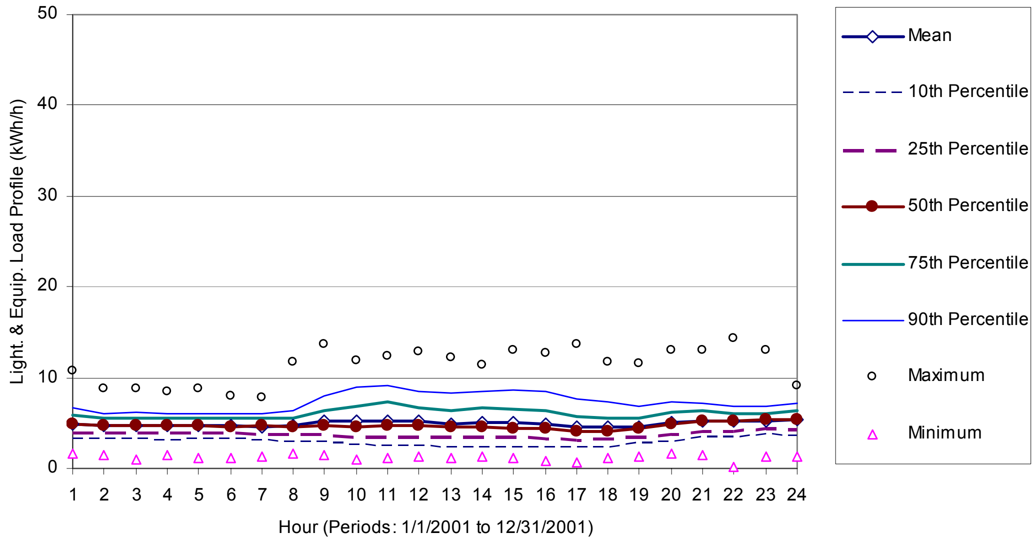


Figure D.26 *Weekday-type of the 2004 conference center electricity use.*
(Note: The dates that are excluded from the weekday profile are as follows: 2/29/04 and 7/25/04).

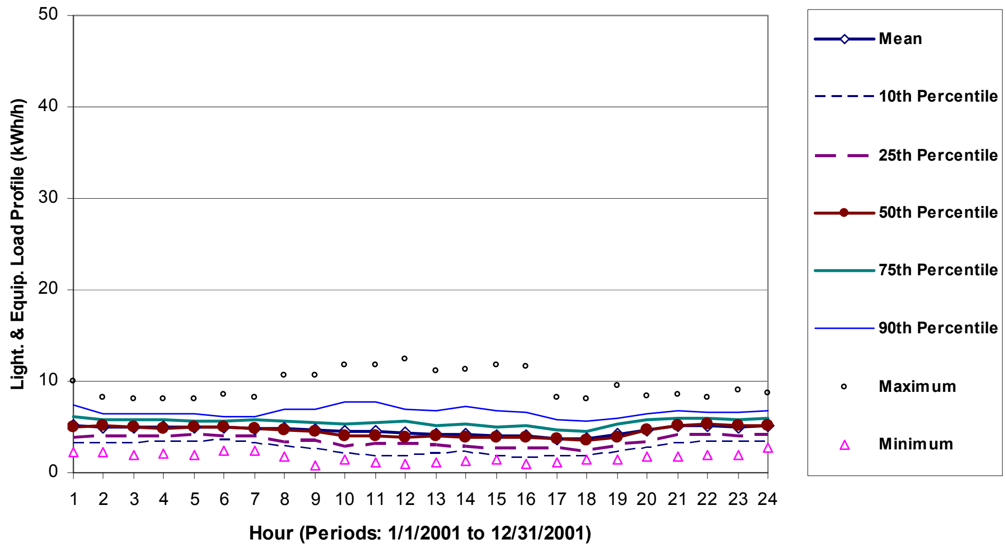


Figure D.27 *Weekend-type of the 2004 conference center electricity use.*
(Note: The dates that are excluded from the weekday profile are as follows: 2/29/04 and 7/25/04).

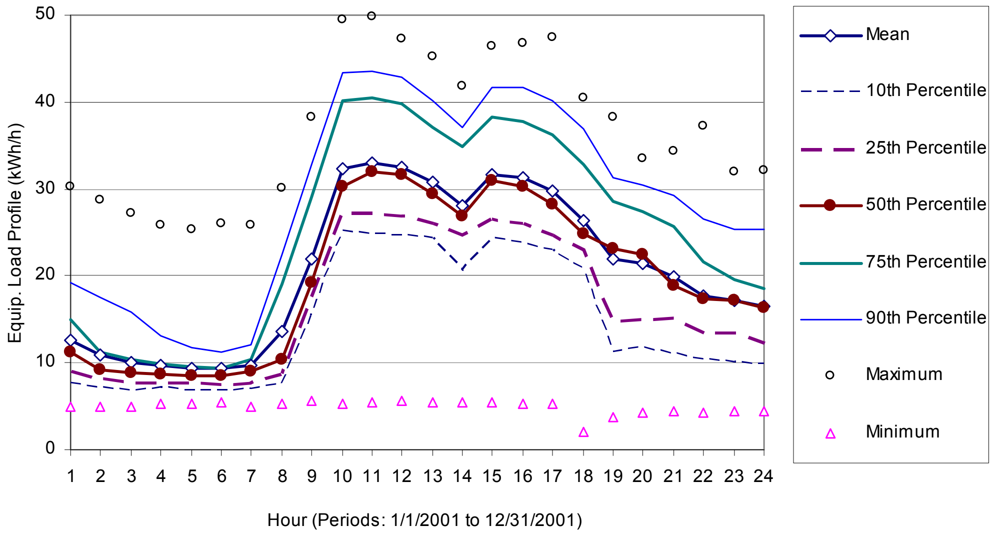


Figure D.28 *Weekday-type of the 2001 senate print shop electricity use (Note: The dates that are excluded from the weekday profile are as follows: 1/1/01, 7/4/01, 11/22/01, 11/23/01, 12/24/01, 12/25/01, and 12/26/01).*

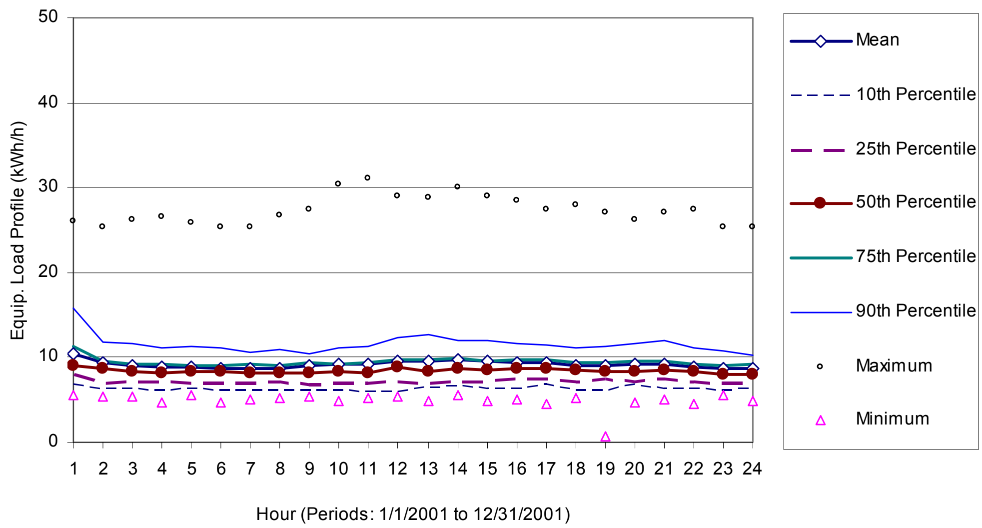


Figure D.29 *Weekend-type of the 2001 senate print shop electricity use (Note: The dates that are excluded from the weekday profile are as follows: 4/1/01 and 9/29/01).*

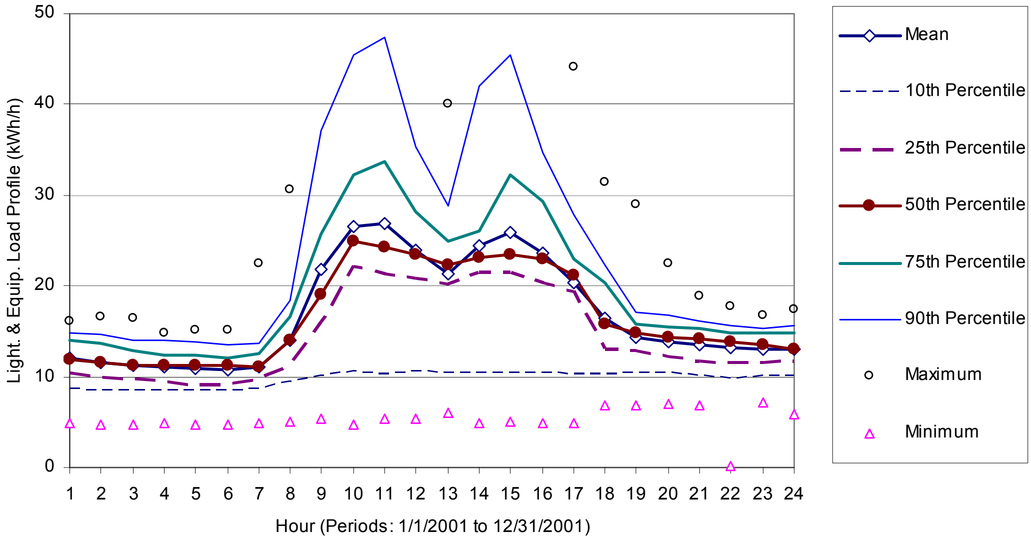


Figure D.30 *Weekday-type of the 2004 senate print shop electricity use.*
(Note: The dates that are excluded from the weekday profile are as follows: 8/9/04).

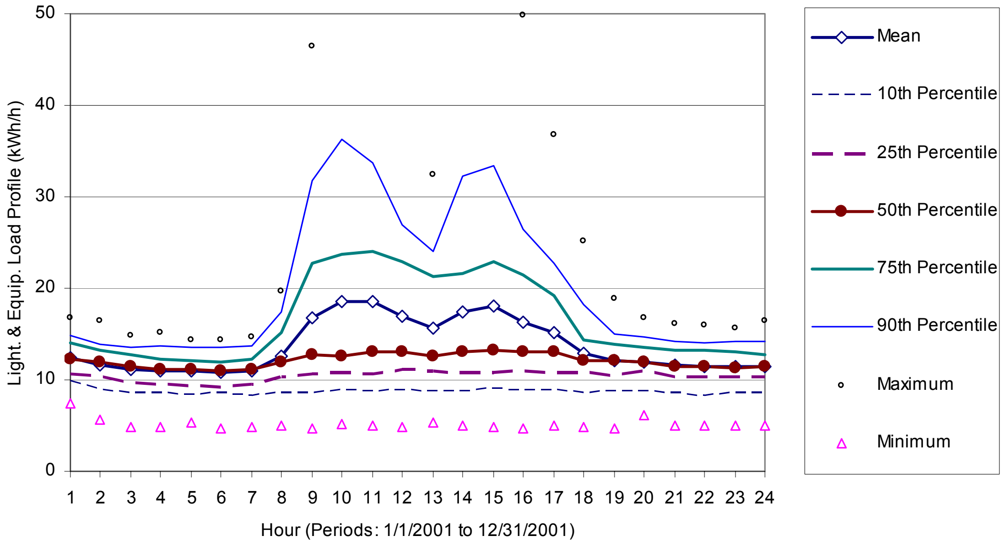


Figure D.31 *Weekend-type of the 2004 senate print shop electricity use.*
(Note: The dates that are excluded from the weekday profile are as follows:
2/29/04 and 7/25/04).

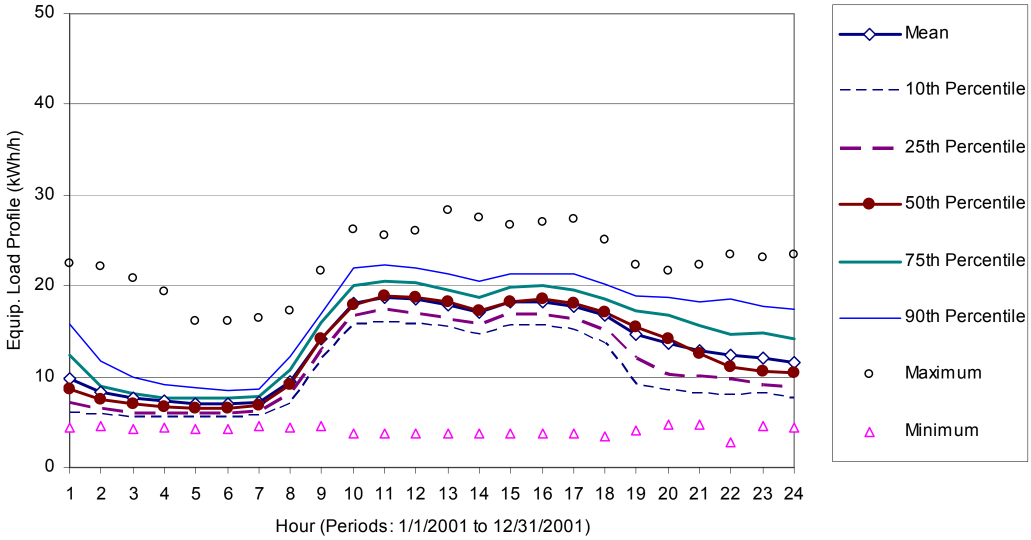


Figure D.32 *Weekday-type of the 2001 TLC print shop electricity use.*
(Note: The dates that are excluded from the weekday profile are as follows:
1/1/01,7/4/01, 11/22/01, 11/23/01, 12/24/01, 12/25/01, and 12/26/01).

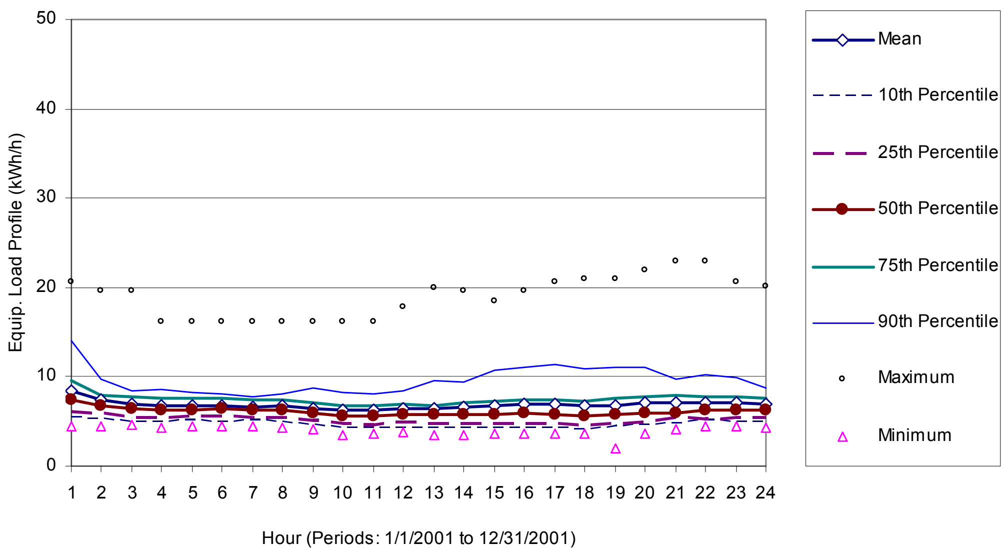


Figure D.33 *Weekend-type of the 2001 TLC print shop electricity use.*
(Note: The dates that are excluded from the weekday profile are as follows: 8/9/04)/01).

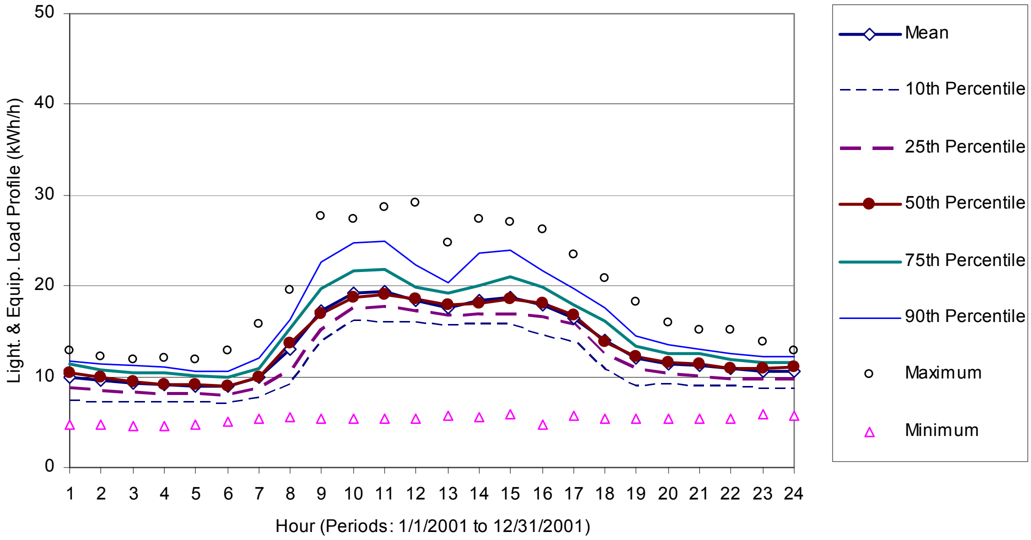


Figure D.34 *Weekday-type of the 2004 TLC print shop electricity use.*
(Note: The dates that are excluded from the weekday profile are as follows: 8/9/04).

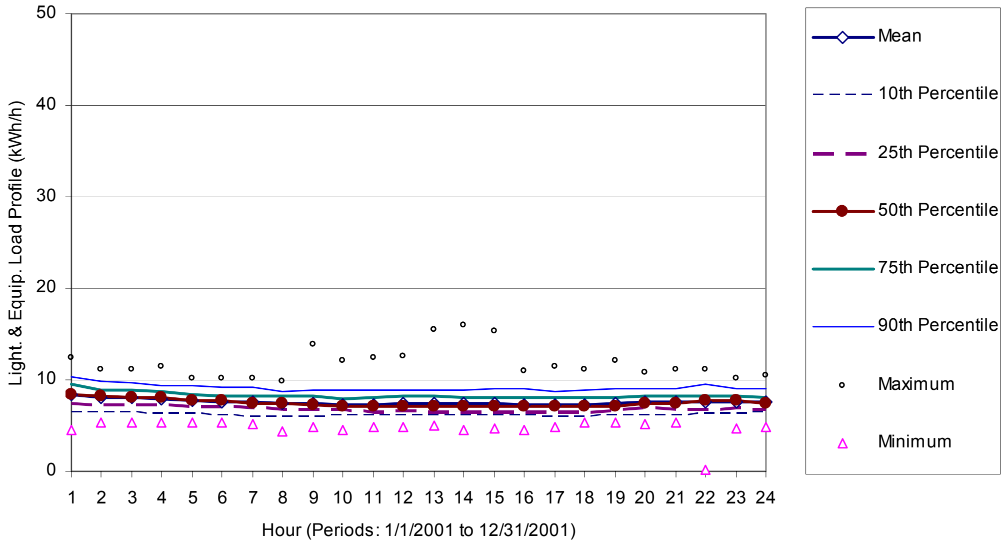


Figure D.35 *Weekend-type of the 2004 TLC print shop electricity use.*
(Note: The dates that are excluded from the weekday profile are as follows: 2/29/04 and 7/25/04).

Table D.8 2001 Conference Center Electricity Use Profile

WEEKDAYS: 2001 Conference Center

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.49	0.62	0.36	0.34	0.38	0.46	0.57	0.69	0.93	0.30
2.00	0.48	0.61	0.34	0.34	0.37	0.45	0.54	0.66	0.92	0.31
3.00	0.47	0.60	0.34	0.34	0.37	0.45	0.55	0.66	0.95	0.31
4.00	0.47	0.60	0.34	0.34	0.37	0.44	0.54	0.64	0.94	0.30
5.00	0.47	0.59	0.34	0.33	0.37	0.44	0.54	0.64	0.93	0.30
6.00	0.47	0.59	0.34	0.33	0.36	0.43	0.54	0.66	0.94	0.29
7.00	0.46	0.59	0.34	0.33	0.36	0.44	0.53	0.63	0.92	0.28
8.00	0.47	0.59	0.34	0.33	0.36	0.44	0.54	0.65	0.96	0.30
9.00	0.42	0.55	0.28	0.27	0.32	0.39	0.49	0.61	0.97	0.18
10.00	0.37	0.54	0.21	0.18	0.24	0.35	0.49	0.58	0.92	0.10
11.00	0.38	0.55	0.20	0.16	0.23	0.36	0.50	0.61	0.85	0.10
12.00	0.38	0.56	0.20	0.15	0.23	0.36	0.51	0.64	0.87	0.09
13.00	0.35	0.53	0.18	0.15	0.21	0.32	0.47	0.60	0.82	0.10
14.00	0.34	0.51	0.17	0.15	0.21	0.31	0.45	0.58	0.83	0.08
15.00	0.36	0.53	0.19	0.15	0.23	0.34	0.48	0.62	0.85	0.09
16.00	0.36	0.53	0.19	0.15	0.23	0.34	0.47	0.59	0.93	0.10
17.00	0.36	0.53	0.18	0.15	0.22	0.33	0.47	0.62	0.83	0.09
18.00	0.34	0.49	0.19	0.15	0.22	0.32	0.44	0.54	0.84	0.08
19.00	0.37	0.51	0.24	0.21	0.27	0.35	0.47	0.58	0.74	0.10
20.00	0.51	0.64	0.37	0.34	0.41	0.51	0.60	0.66	0.89	0.12
21.00	0.47	0.61	0.34	0.32	0.38	0.45	0.54	0.66	0.93	0.15
22.00	0.50	0.64	0.36	0.34	0.38	0.47	0.57	0.72	0.92	0.14
23.00	0.50	0.64	0.37	0.34	0.39	0.49	0.60	0.71	0.93	0.31
24.00	0.51	0.65	0.37	0.34	0.39	0.50	0.59	0.72	1.00	0.31
Daily Values	10.28	13.00	7.57	7.08	8.32	9.90	11.98	13.90	19.93	5.92
Daily Sum from Hourly	10.28	13.79	6.78	6.20	7.49	9.73	12.50	15.27	21.62	4.52

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

WEEKENDS: 2001 Conference Center

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.49	0.64	0.35	0.33	0.37	0.46	0.60	0.73	0.89	0.31
2.00	0.48	0.62	0.35	0.34	0.37	0.46	0.56	0.69	0.92	0.31
3.00	0.47	0.61	0.34	0.34	0.36	0.44	0.55	0.65	0.88	0.31
4.00	0.48	0.61	0.34	0.33	0.36	0.46	0.54	0.66	0.90	0.31
5.00	0.47	0.61	0.33	0.32	0.34	0.44	0.57	0.66	0.85	0.31
6.00	0.47	0.61	0.34	0.34	0.36	0.45	0.55	0.65	0.89	0.31
7.00	0.47	0.60	0.34	0.34	0.36	0.43	0.54	0.65	0.89	0.31
8.00	0.47	0.60	0.33	0.33	0.36	0.44	0.55	0.65	0.89	0.31
9.00	0.36	0.50	0.23	0.23	0.28	0.33	0.43	0.54	0.79	0.15
10.00	0.28	0.42	0.13	0.14	0.16	0.25	0.35	0.50	0.70	0.10
11.00	0.26	0.40	0.11	0.11	0.12	0.22	0.35	0.50	0.64	0.08
12.00	0.26	0.41	0.12	0.12	0.14	0.22	0.35	0.48	0.69	0.10
13.00	0.25	0.40	0.11	0.11	0.14	0.22	0.34	0.45	0.68	0.08
14.00	0.25	0.39	0.11	0.11	0.13	0.21	0.34	0.46	0.69	0.10
15.00	0.25	0.40	0.11	0.11	0.15	0.21	0.34	0.45	0.66	0.09
16.00	0.25	0.39	0.11	0.12	0.14	0.20	0.35	0.43	0.66	0.08
17.00	0.25	0.39	0.10	0.11	0.14	0.21	0.32	0.43	0.69	0.09
18.00	0.26	0.40	0.11	0.12	0.15	0.21	0.35	0.42	0.73	0.08
19.00	0.29	0.43	0.15	0.15	0.17	0.28	0.34	0.46	0.76	0.08
20.00	0.33	0.46	0.20	0.16	0.24	0.32	0.38	0.52	0.67	0.08
21.00	0.38	0.50	0.25	0.24	0.32	0.36	0.41	0.57	0.79	0.14
22.00	0.44	0.57	0.31	0.32	0.34	0.41	0.51	0.60	0.89	0.27
23.00	0.46	0.59	0.33	0.34	0.35	0.42	0.54	0.61	0.87	0.30
24.00	0.45	0.58	0.32	0.33	0.36	0.41	0.54	0.63	0.88	0.31
Daily Values	8.83	11.88	5.79	5.92	6.29	7.97	10.56	12.66	18.34	5.24
Daily Sum from Hourly	8.83	12.13	5.53	5.47	6.18	8.06	10.71	13.37	18.89	4.61

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

Table D.9 2004 Conference Center Electricity Use Profile

WEEKDAYS: 2004 Conference Center

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.34	0.44	0.24	0.22	0.27	0.34	0.41	0.46	0.75	0.12
2.00	0.33	0.41	0.25	0.22	0.27	0.34	0.39	0.43	0.62	0.10
3.00	0.33	0.41	0.24	0.23	0.27	0.33	0.39	0.43	0.62	0.07
4.00	0.33	0.41	0.24	0.22	0.27	0.33	0.39	0.43	0.59	0.10
5.00	0.33	0.41	0.24	0.22	0.27	0.33	0.39	0.43	0.62	0.08
6.00	0.32	0.41	0.24	0.22	0.27	0.32	0.38	0.43	0.56	0.08
7.00	0.32	0.40	0.24	0.22	0.27	0.33	0.38	0.42	0.55	0.09
8.00	0.33	0.43	0.22	0.20	0.26	0.32	0.39	0.45	0.83	0.11
9.00	0.36	0.50	0.22	0.21	0.27	0.33	0.45	0.56	0.95	0.10
10.00	0.36	0.53	0.20	0.18	0.24	0.31	0.48	0.62	0.83	0.07
11.00	0.37	0.54	0.20	0.17	0.24	0.33	0.51	0.64	0.86	0.08
12.00	0.36	0.53	0.20	0.17	0.24	0.33	0.47	0.59	0.90	0.09
13.00	0.35	0.51	0.19	0.15	0.24	0.31	0.45	0.58	0.85	0.08
14.00	0.35	0.51	0.19	0.16	0.24	0.32	0.46	0.59	0.80	0.09
15.00	0.36	0.53	0.19	0.16	0.24	0.31	0.46	0.61	0.92	0.08
16.00	0.34	0.51	0.18	0.15	0.22	0.31	0.44	0.59	0.89	0.06
17.00	0.32	0.47	0.17	0.16	0.22	0.29	0.40	0.54	0.96	0.05
18.00	0.32	0.46	0.18	0.15	0.22	0.29	0.38	0.52	0.82	0.08
19.00	0.32	0.44	0.20	0.19	0.24	0.30	0.38	0.48	0.81	0.09
20.00	0.35	0.48	0.23	0.20	0.26	0.35	0.43	0.52	0.92	0.11
21.00	0.37	0.49	0.25	0.24	0.29	0.36	0.44	0.50	0.92	0.10
22.00	0.36	0.47	0.25	0.24	0.29	0.37	0.42	0.48	1.00	0.01
23.00	0.37	0.46	0.28	0.27	0.31	0.37	0.42	0.48	0.92	0.09
24.00	0.37	0.47	0.27	0.25	0.29	0.37	0.44	0.50	0.64	0.09
Daily Values	8.27	10.41	6.13	5.75	6.73	7.98	10.02	11.21	13.51	3.34
Daily Sum from Hourly	8.27	11.22	5.32	4.83	6.19	7.88	10.17	12.26	19.08	2.03

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

WEEKENDS: 2004 Conference Center

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.36	0.47	0.25	0.22	0.28	0.35	0.43	0.52	0.70	0.15
2.00	0.35	0.43	0.26	0.23	0.28	0.36	0.41	0.45	0.57	0.16
3.00	0.35	0.44	0.26	0.23	0.29	0.35	0.41	0.45	0.57	0.13
4.00	0.35	0.43	0.26	0.23	0.29	0.34	0.41	0.45	0.57	0.15
5.00	0.35	0.43	0.26	0.23	0.29	0.35	0.40	0.45	0.57	0.13
6.00	0.35	0.43	0.26	0.24	0.29	0.35	0.39	0.43	0.59	0.17
7.00	0.34	0.43	0.25	0.23	0.28	0.34	0.41	0.43	0.58	0.17
8.00	0.34	0.47	0.21	0.20	0.24	0.32	0.40	0.49	0.75	0.13
9.00	0.33	0.47	0.20	0.18	0.24	0.31	0.38	0.48	0.74	0.06
10.00	0.32	0.47	0.16	0.15	0.20	0.29	0.37	0.54	0.82	0.10
11.00	0.32	0.47	0.16	0.13	0.22	0.28	0.39	0.54	0.82	0.08
12.00	0.31	0.45	0.16	0.13	0.22	0.27	0.40	0.48	0.87	0.07
13.00	0.30	0.43	0.17	0.14	0.22	0.28	0.36	0.47	0.78	0.08
14.00	0.30	0.43	0.16	0.16	0.20	0.27	0.37	0.50	0.79	0.09
15.00	0.29	0.43	0.15	0.13	0.19	0.27	0.35	0.48	0.83	0.10
16.00	0.28	0.42	0.15	0.11	0.20	0.27	0.36	0.47	0.81	0.07
17.00	0.26	0.37	0.16	0.13	0.19	0.26	0.32	0.40	0.58	0.08
18.00	0.26	0.36	0.15	0.12	0.17	0.25	0.32	0.40	0.57	0.10
19.00	0.29	0.40	0.18	0.16	0.21	0.27	0.37	0.42	0.66	0.10
20.00	0.32	0.43	0.22	0.19	0.23	0.33	0.41	0.45	0.59	0.13
21.00	0.36	0.45	0.26	0.23	0.30	0.36	0.42	0.47	0.59	0.13
22.00	0.36	0.45	0.27	0.24	0.29	0.37	0.42	0.46	0.57	0.14
23.00	0.36	0.44	0.27	0.24	0.29	0.36	0.41	0.46	0.63	0.14
24.00	0.36	0.45	0.26	0.23	0.29	0.36	0.41	0.48	0.61	0.20
Daily Values	7.76	9.76	5.76	5.24	6.15	7.65	9.44	10.37	12.46	3.90
Daily Sum from Hourly	7.76	10.44	5.09	4.49	5.90	7.55	9.31	11.20	16.15	2.85

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

Table D.10 2001 Senate Print Shop Electricity Use Profile

WEEKDAYS: 2001 Senate Print Shop

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.25	0.35	0.15	0.15	0.18	0.23	0.30	0.39	0.61	0.10
2.00	0.22	0.31	0.12	0.14	0.16	0.18	0.22	0.35	0.58	0.10
3.00	0.20	0.29	0.11	0.14	0.15	0.18	0.21	0.32	0.55	0.10
4.00	0.20	0.28	0.11	0.14	0.15	0.17	0.20	0.26	0.52	0.10
5.00	0.19	0.26	0.11	0.14	0.15	0.17	0.19	0.23	0.51	0.10
6.00	0.19	0.26	0.11	0.14	0.15	0.17	0.19	0.23	0.52	0.11
7.00	0.19	0.26	0.12	0.14	0.15	0.18	0.21	0.24	0.52	0.10
8.00	0.27	0.39	0.15	0.15	0.17	0.21	0.38	0.45	0.60	0.10
9.00	0.44	0.58	0.30	0.31	0.35	0.39	0.58	0.66	0.77	0.11
10.00	0.65	0.82	0.48	0.51	0.55	0.61	0.80	0.87	0.99	0.10
11.00	0.66	0.84	0.49	0.50	0.55	0.64	0.81	0.87	1.00	0.11
12.00	0.65	0.82	0.48	0.49	0.54	0.64	0.80	0.86	0.95	0.11
13.00	0.62	0.77	0.47	0.49	0.52	0.59	0.74	0.80	0.91	0.11
14.00	0.56	0.70	0.42	0.41	0.49	0.54	0.70	0.74	0.84	0.11
15.00	0.63	0.79	0.48	0.49	0.53	0.62	0.77	0.83	0.93	0.11
16.00	0.63	0.79	0.47	0.48	0.52	0.61	0.76	0.83	0.94	0.10
17.00	0.60	0.76	0.44	0.46	0.49	0.57	0.73	0.80	0.95	0.10
18.00	0.53	0.67	0.38	0.41	0.46	0.50	0.66	0.74	0.81	0.04
19.00	0.44	0.59	0.29	0.22	0.29	0.46	0.57	0.63	0.77	0.07
20.00	0.43	0.57	0.29	0.23	0.30	0.45	0.55	0.61	0.67	0.08
21.00	0.40	0.53	0.27	0.22	0.30	0.38	0.52	0.59	0.69	0.09
22.00	0.35	0.47	0.24	0.21	0.27	0.35	0.43	0.53	0.75	0.08
23.00	0.34	0.45	0.24	0.20	0.27	0.34	0.39	0.51	0.64	0.09
24.00	0.33	0.44	0.22	0.20	0.24	0.33	0.37	0.51	0.65	0.09
Daily Values	9.97	11.94	8.00	7.84	8.99	9.88	11.51	12.36	14.31	2.70
Daily Sum from Hourly	9.97	13.00	6.94	6.98	7.96	9.49	12.08	13.86	17.64	2.34

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

WEEKENDS: 2001 Senate Print Shop

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.21	0.30	0.12	0.14	0.16	0.18	0.23	0.32	0.52	0.11
2.00	0.19	0.27	0.10	0.13	0.14	0.17	0.19	0.24	0.51	0.11
3.00	0.18	0.26	0.10	0.13	0.14	0.17	0.18	0.23	0.53	0.11
4.00	0.18	0.25	0.10	0.12	0.14	0.16	0.18	0.22	0.53	0.09
5.00	0.18	0.24	0.11	0.13	0.14	0.17	0.18	0.22	0.52	0.11
6.00	0.17	0.24	0.11	0.12	0.14	0.17	0.18	0.22	0.51	0.09
7.00	0.17	0.24	0.11	0.12	0.14	0.16	0.18	0.21	0.51	0.10
8.00	0.18	0.25	0.10	0.12	0.14	0.16	0.18	0.22	0.54	0.10
9.00	0.18	0.27	0.10	0.12	0.14	0.16	0.19	0.21	0.55	0.11
10.00	0.19	0.28	0.09	0.12	0.14	0.17	0.18	0.22	0.61	0.10
11.00	0.19	0.28	0.09	0.12	0.14	0.16	0.19	0.23	0.62	0.10
12.00	0.19	0.28	0.10	0.12	0.14	0.18	0.20	0.25	0.58	0.11
13.00	0.19	0.29	0.10	0.13	0.14	0.17	0.19	0.26	0.58	0.10
14.00	0.19	0.29	0.10	0.13	0.14	0.17	0.20	0.24	0.60	0.11
15.00	0.19	0.28	0.10	0.13	0.14	0.17	0.19	0.24	0.58	0.10
16.00	0.19	0.28	0.10	0.13	0.15	0.17	0.19	0.23	0.57	0.10
17.00	0.19	0.27	0.11	0.13	0.15	0.17	0.19	0.23	0.55	0.09
18.00	0.18	0.26	0.11	0.12	0.14	0.17	0.19	0.22	0.56	0.10
19.00	0.18	0.25	0.11	0.12	0.15	0.17	0.19	0.23	0.54	0.01
20.00	0.18	0.26	0.11	0.13	0.14	0.17	0.19	0.23	0.53	0.09
21.00	0.19	0.26	0.11	0.13	0.15	0.17	0.19	0.24	0.54	0.10
22.00	0.18	0.25	0.11	0.13	0.14	0.17	0.19	0.22	0.55	0.09
23.00	0.17	0.24	0.11	0.12	0.14	0.16	0.18	0.22	0.51	0.11
24.00	0.17	0.24	0.11	0.13	0.14	0.16	0.18	0.21	0.51	0.10
Daily Values	4.41	6.05	2.76	3.02	3.57	4.19	4.58	5.75	12.22	2.55
Daily Sum from Hourly	4.41	6.32	2.49	3.02	3.45	4.02	4.55	5.56	13.14	2.36

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

Table D.11 2004 Senate Print Shop Electricity Use Profile

WEEKDAYS: 2004 Senatet Printshop Electricity Use

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.39	0.48	0.31	0.24	0.35	0.42	0.45	0.48	0.54	0.20
2.00	0.35	0.44	0.26	0.21	0.26	0.38	0.42	0.44	0.50	0.19
3.00	0.30	0.39	0.22	0.21	0.22	0.27	0.39	0.42	0.46	0.18
4.00	0.28	0.36	0.20	0.21	0.22	0.24	0.35	0.40	0.45	0.18
5.00	0.27	0.35	0.20	0.20	0.21	0.24	0.34	0.39	0.46	0.17
6.00	0.28	0.36	0.21	0.21	0.22	0.26	0.34	0.40	0.51	0.17
7.00	0.34	0.42	0.26	0.24	0.28	0.34	0.39	0.45	0.56	0.20
8.00	0.50	0.63	0.37	0.33	0.38	0.55	0.61	0.65	0.72	0.21
9.00	0.69	0.81	0.56	0.57	0.62	0.74	0.78	0.80	0.82	0.21
10.00	0.79	0.92	0.67	0.73	0.80	0.82	0.85	0.86	0.91	0.21
11.00	0.83	0.96	0.71	0.77	0.83	0.86	0.88	0.91	0.95	0.21
12.00	0.84	0.97	0.71	0.79	0.84	0.87	0.89	0.92	0.97	0.21
13.00	0.83	0.96	0.71	0.77	0.83	0.86	0.89	0.92	1.00	0.21
14.00	0.82	0.95	0.70	0.77	0.82	0.85	0.88	0.91	1.00	0.20
15.00	0.82	0.94	0.69	0.76	0.82	0.84	0.87	0.91	0.97	0.20
16.00	0.80	0.92	0.67	0.74	0.79	0.82	0.85	0.89	0.95	0.20
17.00	0.75	0.87	0.63	0.67	0.73	0.77	0.82	0.87	0.94	0.20
18.00	0.67	0.78	0.55	0.58	0.63	0.67	0.75	0.79	0.84	0.20
19.00	0.59	0.68	0.50	0.51	0.56	0.59	0.65	0.68	0.72	0.20
20.00	0.53	0.61	0.46	0.48	0.51	0.54	0.58	0.61	0.65	0.20
21.00	0.50	0.57	0.44	0.46	0.48	0.51	0.53	0.57	0.62	0.20
22.00	0.48	0.54	0.41	0.42	0.45	0.48	0.51	0.56	0.60	0.21
23.00	0.45	0.50	0.40	0.40	0.43	0.46	0.48	0.51	0.55	0.21
24.00	0.45	0.50	0.40	0.41	0.43	0.45	0.48	0.50	0.55	0.20
Daily Values	13.57	15.27	11.87	12.65	13.33	13.76	14.47	14.93	16.11	5.21
Daily Sum from Hourly	13.57	15.88	11.25	11.68	12.72	13.82	14.98	15.83	17.26	4.78

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

WEEKENDS: 2004 Senate Printshop Electricity Use

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.34	0.43	0.25	0.21	0.26	0.36	0.42	0.45	0.54	0.20
2.00	0.31	0.39	0.23	0.21	0.22	0.31	0.39	0.42	0.46	0.19
3.00	0.28	0.35	0.20	0.20	0.21	0.24	0.35	0.39	0.44	0.18
4.00	0.26	0.33	0.20	0.20	0.21	0.23	0.30	0.37	0.42	0.19
5.00	0.26	0.32	0.20	0.20	0.21	0.23	0.30	0.36	0.41	0.18
6.00	0.26	0.32	0.20	0.20	0.21	0.23	0.30	0.36	0.42	0.19
7.00	0.26	0.32	0.20	0.20	0.22	0.23	0.30	0.35	0.41	0.18
8.00	0.27	0.34	0.19	0.20	0.21	0.23	0.31	0.35	0.61	0.19
9.00	0.27	0.36	0.18	0.20	0.21	0.24	0.31	0.39	0.75	0.19
10.00	0.28	0.38	0.18	0.21	0.22	0.24	0.31	0.39	0.82	0.19
11.00	0.29	0.38	0.19	0.21	0.23	0.25	0.33	0.37	0.82	0.19
12.00	0.29	0.39	0.19	0.22	0.23	0.27	0.32	0.39	0.83	0.19
13.00	0.30	0.40	0.20	0.21	0.24	0.27	0.33	0.40	0.84	0.19
14.00	0.30	0.40	0.20	0.22	0.24	0.28	0.32	0.41	0.83	0.19
15.00	0.31	0.41	0.21	0.22	0.25	0.28	0.33	0.41	0.84	0.19
16.00	0.31	0.40	0.21	0.22	0.25	0.29	0.33	0.40	0.83	0.19
17.00	0.30	0.40	0.21	0.22	0.24	0.29	0.33	0.40	0.78	0.19
18.00	0.30	0.39	0.21	0.22	0.25	0.28	0.33	0.41	0.71	0.19
19.00	0.30	0.38	0.22	0.22	0.24	0.28	0.32	0.40	0.64	0.19
20.00	0.29	0.37	0.22	0.22	0.24	0.28	0.31	0.40	0.61	0.18
21.00	0.29	0.36	0.22	0.22	0.24	0.28	0.32	0.39	0.60	0.19
22.00	0.29	0.36	0.22	0.22	0.24	0.27	0.32	0.39	0.54	0.18
23.00	0.29	0.35	0.22	0.22	0.23	0.27	0.32	0.39	0.49	0.19
24.00	0.28	0.35	0.21	0.21	0.23	0.26	0.31	0.39	0.49	0.19
Daily Values	6.92	8.59	5.25	5.37	5.74	6.38	7.85	8.90	14.23	4.60
Daily Sum from Hourly	6.92	8.88	4.95	5.09	5.54	6.41	7.80	9.38	15.15	4.53

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

Table D.12 2001 TLC Print Shop Electricity Use Profile

WEEKDAYS: 2001 TLC Print Shop

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.35	0.48	0.22	0.21	0.25	0.31	0.43	0.56	0.79	0.15
2.00	0.29	0.41	0.18	0.20	0.23	0.26	0.31	0.42	0.78	0.16
3.00	0.27	0.36	0.18	0.20	0.21	0.25	0.29	0.35	0.74	0.15
4.00	0.26	0.34	0.18	0.19	0.21	0.24	0.27	0.32	0.68	0.15
5.00	0.25	0.31	0.18	0.19	0.21	0.23	0.27	0.31	0.57	0.15
6.00	0.25	0.31	0.19	0.19	0.21	0.23	0.27	0.30	0.57	0.15
7.00	0.25	0.31	0.20	0.20	0.22	0.24	0.27	0.31	0.58	0.16
8.00	0.33	0.41	0.26	0.25	0.28	0.32	0.38	0.43	0.61	0.15
9.00	0.50	0.59	0.41	0.42	0.45	0.50	0.56	0.60	0.76	0.16
10.00	0.64	0.76	0.52	0.56	0.59	0.63	0.70	0.77	0.93	0.13
11.00	0.66	0.78	0.53	0.56	0.61	0.67	0.73	0.79	0.90	0.13
12.00	0.65	0.77	0.53	0.56	0.60	0.66	0.72	0.77	0.92	0.13
13.00	0.63	0.75	0.52	0.54	0.58	0.64	0.69	0.75	1.00	0.13
14.00	0.60	0.72	0.49	0.51	0.56	0.61	0.66	0.73	0.97	0.13
15.00	0.64	0.76	0.52	0.55	0.60	0.64	0.70	0.75	0.94	0.13
16.00	0.64	0.76	0.52	0.55	0.60	0.65	0.70	0.75	0.95	0.13
17.00	0.63	0.75	0.51	0.53	0.58	0.64	0.69	0.75	0.96	0.13
18.00	0.59	0.70	0.47	0.48	0.54	0.60	0.65	0.71	0.88	0.12
19.00	0.52	0.65	0.39	0.32	0.43	0.54	0.61	0.67	0.79	0.14
20.00	0.48	0.62	0.34	0.30	0.36	0.50	0.59	0.66	0.76	0.17
21.00	0.45	0.59	0.32	0.29	0.36	0.44	0.55	0.64	0.79	0.17
22.00	0.43	0.57	0.29	0.28	0.35	0.39	0.52	0.65	0.83	0.10
23.00	0.43	0.56	0.29	0.29	0.32	0.37	0.52	0.63	0.81	0.16
24.00	0.41	0.55	0.27	0.27	0.31	0.37	0.50	0.62	0.83	0.15
Daily Values	11.15	13.05	9.24	9.13	10.40	11.19	12.17	13.35	16.53	3.63
Daily Sum from Hourly	11.15	13.81	8.49	8.64	9.64	10.92	12.58	14.23	19.33	3.45

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

WEEKENDS: 2001 TLC Print Shop

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.30	0.42	0.17	0.19	0.21	0.26	0.34	0.49	0.73	0.15
2.00	0.26	0.35	0.17	0.19	0.21	0.24	0.28	0.34	0.69	0.15
3.00	0.25	0.33	0.16	0.18	0.19	0.23	0.27	0.30	0.69	0.17
4.00	0.24	0.31	0.17	0.18	0.19	0.22	0.27	0.30	0.57	0.15
5.00	0.24	0.30	0.17	0.18	0.20	0.22	0.26	0.29	0.57	0.15
6.00	0.24	0.30	0.17	0.18	0.20	0.23	0.27	0.29	0.57	0.16
7.00	0.23	0.30	0.17	0.18	0.19	0.22	0.26	0.27	0.57	0.15
8.00	0.24	0.31	0.17	0.18	0.19	0.22	0.26	0.28	0.57	0.15
9.00	0.23	0.31	0.15	0.17	0.18	0.21	0.25	0.31	0.57	0.14
10.00	0.22	0.31	0.13	0.15	0.17	0.20	0.24	0.29	0.57	0.12
11.00	0.22	0.31	0.13	0.15	0.17	0.20	0.24	0.28	0.57	0.13
12.00	0.23	0.32	0.13	0.15	0.17	0.20	0.24	0.30	0.63	0.13
13.00	0.23	0.33	0.13	0.15	0.17	0.20	0.24	0.34	0.70	0.12
14.00	0.23	0.34	0.13	0.15	0.17	0.20	0.25	0.33	0.69	0.12
15.00	0.24	0.34	0.13	0.15	0.17	0.20	0.25	0.38	0.65	0.13
16.00	0.24	0.35	0.13	0.15	0.17	0.21	0.26	0.39	0.69	0.13
17.00	0.24	0.36	0.13	0.15	0.17	0.20	0.26	0.40	0.73	0.13
18.00	0.24	0.36	0.13	0.14	0.17	0.20	0.26	0.39	0.74	0.13
19.00	0.24	0.35	0.13	0.16	0.17	0.20	0.27	0.39	0.74	0.07
20.00	0.25	0.36	0.14	0.16	0.18	0.21	0.27	0.39	0.77	0.13
21.00	0.25	0.36	0.14	0.17	0.19	0.21	0.28	0.35	0.81	0.14
22.00	0.25	0.35	0.15	0.18	0.19	0.22	0.27	0.36	0.81	0.16
23.00	0.25	0.34	0.15	0.18	0.19	0.22	0.27	0.35	0.73	0.15
24.00	0.25	0.34	0.15	0.18	0.19	0.22	0.27	0.31	0.71	0.15
Daily Values	5.79	7.80	3.78	4.05	4.45	5.20	6.49	7.51	13.98	3.48
Daily Sum from Hourly	5.79	8.04	3.54	3.98	4.40	5.13	6.33	8.11	16.08	3.35

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

Table D.13 2004 TLC Print Shop Electricity Use Profile

WEEKDAYS: 2004 TLC Print Shop

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.34	0.40	0.28	0.25	0.30	0.36	0.39	0.41	0.44	0.16
2.00	0.33	0.38	0.27	0.25	0.29	0.34	0.37	0.39	0.42	0.16
3.00	0.32	0.37	0.27	0.25	0.28	0.33	0.36	0.38	0.41	0.15
4.00	0.31	0.37	0.26	0.24	0.28	0.32	0.36	0.38	0.42	0.15
5.00	0.31	0.36	0.26	0.24	0.28	0.31	0.35	0.36	0.41	0.16
6.00	0.31	0.35	0.26	0.24	0.27	0.31	0.34	0.36	0.44	0.17
7.00	0.34	0.40	0.28	0.26	0.30	0.34	0.37	0.42	0.54	0.18
8.00	0.45	0.54	0.35	0.32	0.36	0.47	0.52	0.56	0.67	0.19
9.00	0.60	0.73	0.46	0.47	0.52	0.58	0.68	0.78	0.95	0.19
10.00	0.66	0.80	0.52	0.56	0.60	0.65	0.74	0.85	0.94	0.19
11.00	0.67	0.81	0.52	0.55	0.61	0.65	0.75	0.86	0.99	0.19
12.00	0.63	0.76	0.51	0.55	0.59	0.64	0.68	0.77	1.00	0.18
13.00	0.60	0.71	0.50	0.54	0.58	0.62	0.66	0.70	0.85	0.20
14.00	0.63	0.76	0.50	0.54	0.58	0.62	0.69	0.81	0.94	0.19
15.00	0.65	0.79	0.51	0.54	0.58	0.64	0.72	0.82	0.93	0.20
16.00	0.62	0.75	0.49	0.50	0.57	0.62	0.68	0.75	0.90	0.16
17.00	0.57	0.67	0.46	0.48	0.54	0.58	0.62	0.68	0.80	0.20
18.00	0.48	0.58	0.38	0.37	0.43	0.48	0.56	0.60	0.72	0.19
19.00	0.41	0.48	0.34	0.31	0.38	0.42	0.46	0.50	0.63	0.19
20.00	0.39	0.45	0.33	0.31	0.36	0.40	0.43	0.46	0.55	0.18
21.00	0.39	0.44	0.33	0.31	0.35	0.39	0.43	0.45	0.52	0.18
22.00	0.37	0.42	0.32	0.31	0.34	0.37	0.41	0.43	0.52	0.19
23.00	0.37	0.41	0.32	0.30	0.34	0.37	0.40	0.42	0.48	0.20
24.00	0.37	0.41	0.32	0.30	0.34	0.38	0.40	0.42	0.44	0.20
Daily Values	11.11	12.56	9.65	9.89	10.69	11.32	11.96	12.50	13.25	4.52
Daily Sum from Hourly	11.11	13.17	9.04	8.99	10.08	11.17	12.37	13.56	15.91	4.34

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

WEEKENDS: 2004 TLC PrintShop

Hour	Mean	Mean+1StD	Mean-1StD	10th Perctl	25th Perctl	50th Perctl	75th Perctl	90th Perctl	Maximum	Minimum
1.00	0.29	0.34	0.24	0.22	0.26	0.29	0.32	0.36	0.43	0.15
2.00	0.28	0.32	0.24	0.22	0.25	0.28	0.31	0.34	0.38	0.18
3.00	0.28	0.32	0.24	0.22	0.25	0.28	0.30	0.33	0.38	0.19
4.00	0.27	0.31	0.23	0.22	0.25	0.28	0.30	0.32	0.40	0.18
5.00	0.27	0.30	0.23	0.21	0.24	0.27	0.29	0.32	0.35	0.18
6.00	0.26	0.30	0.23	0.21	0.24	0.26	0.28	0.32	0.35	0.19
7.00	0.26	0.30	0.22	0.21	0.24	0.26	0.29	0.32	0.35	0.18
8.00	0.26	0.29	0.22	0.21	0.23	0.25	0.28	0.30	0.34	0.15
9.00	0.25	0.30	0.21	0.21	0.23	0.25	0.28	0.31	0.48	0.16
10.00	0.25	0.29	0.21	0.21	0.23	0.24	0.27	0.31	0.42	0.15
11.00	0.25	0.29	0.21	0.21	0.22	0.24	0.28	0.31	0.43	0.16
12.00	0.25	0.30	0.21	0.21	0.23	0.24	0.28	0.31	0.43	0.16
13.00	0.25	0.30	0.20	0.21	0.22	0.24	0.28	0.31	0.53	0.17
14.00	0.25	0.30	0.21	0.21	0.22	0.24	0.28	0.31	0.55	0.15
15.00	0.25	0.30	0.21	0.21	0.22	0.24	0.27	0.31	0.53	0.16
16.00	0.25	0.29	0.21	0.21	0.22	0.24	0.28	0.31	0.37	0.15
17.00	0.25	0.29	0.21	0.21	0.22	0.24	0.28	0.30	0.40	0.16
18.00	0.25	0.29	0.21	0.21	0.22	0.24	0.28	0.31	0.38	0.18
19.00	0.26	0.30	0.21	0.21	0.23	0.24	0.28	0.31	0.42	0.18
20.00	0.26	0.30	0.22	0.21	0.24	0.25	0.29	0.31	0.37	0.18
21.00	0.26	0.30	0.22	0.21	0.23	0.26	0.29	0.31	0.38	0.18
22.00	0.26	0.31	0.21	0.21	0.23	0.26	0.28	0.33	0.38	0.00
23.00	0.26	0.30	0.22	0.21	0.24	0.26	0.28	0.31	0.35	0.16
24.00	0.26	0.30	0.22	0.22	0.23	0.25	0.28	0.31	0.36	0.16
Daily Values	6.24	7.15	5.34	5.31	5.67	6.21	6.81	7.40	9.02	4.13
Daily Sum from Hourly	6.24	7.25	5.24	5.10	5.61	6.15	6.84	7.55	9.74	3.91

Daily Values: The Daily results as the statistics are applied on daily data.

Daily Sum from Hourly: The aggregated Daily results as the statistics are applied on Hour-of-Day data.

APPENDIX E

CALIBRATION OF SENSORS

E.1 Temperature and Relative Humidity (RH) Sensors Calibration

The temperature and RH of the portable data loggers were measured at three calibration points, which were set at high (about 104 F), normal (about 86F), and low (44F) temperature. This experiment follows the ASTM standard practice (ASTM 1996) for maintaining constant relative humidity by means of aqueous solutions. Standard relative humidity environments are generated using selected aqueous saturated salt solutions. Table E.1 shows the three types of salt characteristic values at three temperature conditions. Linear regression equations were developed to account for RH variation according to temperature variation. Figure E.1 shows the linear Regression Model for the RH Scale Correction based on the values described in Table E.1. The RH verification with saturated salt-water solution was performed as the following procedure:

1) Select a salt of characteristic value from Table E.1.
2) Place a quantity of the selected salt in the bottom of a container or an insert tray to a depth of about 4cm for low RH salts, or a depth of about 1.5 cm for high RH salts. The container should be small to minimize the influence of any temperature variations acting upon the container and contents.
3) Add water in about 2-mL increments, stirring well after each addition, until the salt can absorb no more water as evidenced by free liquid.
4) Close the container and allow more then 1 hour for temperature stabilization.
5) Insert the portable data loggers into the container.
6) Put the container with the portable data logger into a refrigerator maintained at desired temperature.
7) Repeat it at different temperature conditions.
8) Repeat the whole process with other salt solutions that can maintain different RH.

Table E.1 Equilibrium RH Values for Selected Saturated Salt Solutions

Temperature Conditions	Magnesium Chloride (Variation)	Sodium Chloride (Variation)	Conditions
Cold (44F)	33.47 (± 0.24)	75.67 (± 0.22)	Refrigerator on
Normal (86F)	32.44 (± 0.14)	75.09 (± 0.11)	Refrigerator off
Hot (104F)	31.60 (± 0.13)	74.68 (± 0.13)	Refrigerator off with a ramp
Regression Equation	Y=-0.0323X+35.068	Y=-0.0157X+76.362	Ignored variation

(Source: Greenspan, L. 1977. Humidity fixed points of binary saturated aqueous solutions, *Journal of Research of the National Bureau of Standard,* 81(1): 89-96.)

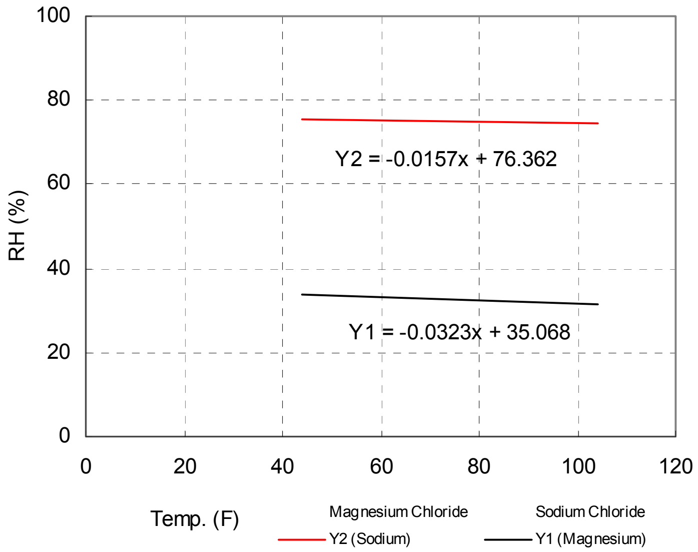


Figure E.1 *Linear regression model for RH sensor scale correction*

Tables E.2 and E.3 show the results of temperature and RH measurements in Magnesium Chloride Solution (RH=32%) and in Magnesium Chloride Solution (RH=75%), respectively. Table 4.24 compares the sensor accuracy with measured results in terms of accuracy range between measured and manufacturer data for the portable data loggers used in this study. Figure E.2 and E.3 show the graphical results of temperature and RH measurements in Magnesium Chloride Solution (RH=32%) and in Magnesium Chloride Solution (RH=75%), respectively. Figure E.4 through E.11 show the time-series plots of the measured data at three temperature mode for the portable data loggers.

Table E.2 Temperature and RH Measurement Results in Magnesium Chloride Solution (RH=32%)

	Measured Temp. (F)			Temp. Diff. (F)		Relative Humidity (%)				RH. Diff.(%)	
	Cor. RTD	HOBO1	HOBO2	HOBO1	HOBO2	REF1	REF2	HOBO1	HOBO2	HOBO1	HOBO2
HOT	104.23	104.23	103.41	0.00	0.82	31.70	31.73	27.20	27.90	4.50	3.83
Normal	86.64	85.83	86.55	0.81	0.09	32.30	32.27	29.30	29.10	3.00	3.17
Cold	43.07	43.19	43.19	-0.12	-0.12	33.67	33.67	33.10	33.10	0.57	0.57

	Measured Temp. (F)			Temp. Diff. (F)		Relative Humidity (%)				RH. Diff.(%)	
	Cor. RTD	HOBO3	HOBO4	HOBO3	HOBO4	REF1	REF2	HOBO3	HOBO4	HOBO3	HOBO4
HOT	97.15	97.04	97.04	0.11	0.11	31.93	31.93	26.90	27.90	5.03	4.03
Normal	86.38	85.83	85.10	0.55	1.28	32.30	32.32	29.20	29.90	3.10	2.42
Cold	43.06	43.92	43.19	-0.86	-0.13	33.65	33.67	32.90	33.40	0.75	0.27

	Measured Temp. (F)			Temp. Diff. (F)		Relative Humidity (%)				RH. Diff.(%)	
	Cor. RTD	HOBO5	HOBO6	HOBO5	HOBO6	REF1	REF2	HOBO5	HOBO6	HOBO5	HOBO6
HOT	104.95	106.73	105.06	-1.78	-0.11	31.62	31.67	28.10	27.90	3.52	3.77
Normal	85.70	86.55	86.55	-0.85	-0.85	32.27	32.27	30.40	29.40	1.87	2.87
Cold	43.59	43.92	43.92	-0.34	-0.34	33.65	33.65	34.10	33.50	-0.45	0.15

	Measured Temp. (F)			Temp. Diff. (F)		Relative Humidity (%)				RH. Diff.(%)	
	Cor. RTD	HOBO7	HOBO8	HOBO7	HOBO8	REF1	REF2	HOBO7	HOBO8	HOBO7	HOBO8
HOT	104.86	103.41	105.06	1.45	-0.20	31.73	31.67	28.60	28.30	3.13	3.37
Normal	87.07	86.55	86.55	0.52	0.52	32.27	32.27	29.40	29.70	2.87	2.57
Cold	43.13	43.19	43.19	-0.06	-0.06	33.67	33.67	33.10	33.40	0.57	0.27

Table E.3 Temperature and RH Measurement Results in Magnesium Chloride Solution (RH=75%)

	Measured Temp. (F)			Temp. Diff. (F)		Relative Humidity (%)				RH. Diff.(%)	
	Cor. RTD	HOBO1	HOBO2	HOBO1	HOBO2	REF1	REF2	HOBO1	HOBO2	HOBO1	HOBO2
HOT	106.75	111.03	110.16	-4.28	-3.41	74.62	74.63	62.20	62.80	**12.42**	11.83
Normal	86.31	85.83	85.83	0.48	0.48	75.01	75.01	70.40	67.20	4.23	7.81
Cold	54.02	54.58	54.58	-0.56	-0.56	75.51	75.51	75.60	72.90	-0.09	2.61

	Measured Temp. (F)			Temp. Diff. (F)		Relative Humidity (%)				RH. Diff.(%)	
	Cor. RTD	HOBO3	HOBO4	HOBO3	HOBO4	REF3	REF4	HOBO3	HOBO4	HOBO3	HOBO4
HOT	105.62	108.43	107.58	-2.81	-1.96	74.66	74.67	63.40	66.50	11.26	8.17
Normal	85.32	87.28	86.55	-1.96	-1.23	74.99	75.00	68.30	70.40	6.69	4.60
Cold	54.02	54.58	54.58	-0.56	-0.56	75.51	75.51	75.60	72.90	**-0.09**	2.61

	Measured Temp. (F)			Temp. Diff. (F)		Relative Humidity (%)				RH. Diff.(%)	
	Cor. RTD	HOBO5	HOBO6	HOBO5	HOBO6	REF5	REF6	HOBO5	HOBO6	HOBO5	HOBO6
HOT	104.78	107.58	107.58	-2.80	-2.80	74.67	74.67	66.50	63.50	8.17	11.17
Normal	85.28	87.28	86.55	-2.00	-1.27	74.99	75.00	70.30	67.70	4.69	7.30
Cold	53.81	53.89	54.58	**-0.08**	-0.77	75.52	75.51	75.70	72.90	-0.18	2.61

	Measured Temp. (F)			Temp. Diff. (F)		Relative Humidity (%)				RH. Diff.(%)	
	Cor. RTD	HOBO7	HOBO8	HOBO7	HOBO8	REF7	REF8	HOBO7	HOBO8	HOBO7	HOBO8
HOT	103.88	108.43	108.43	**-4.55**	-4.55	74.66	74.66	64.60	65.80	10.06	8.86
Normal	85.07	86.55	86.55	-1.48	-1.48	75.00	75.00	68.40	69.00	6.60	6.00
Cold	53.68	53.89	54.58	-0.21	-0.90	75.52	75.51	74.90	74.90	0.62	0.61

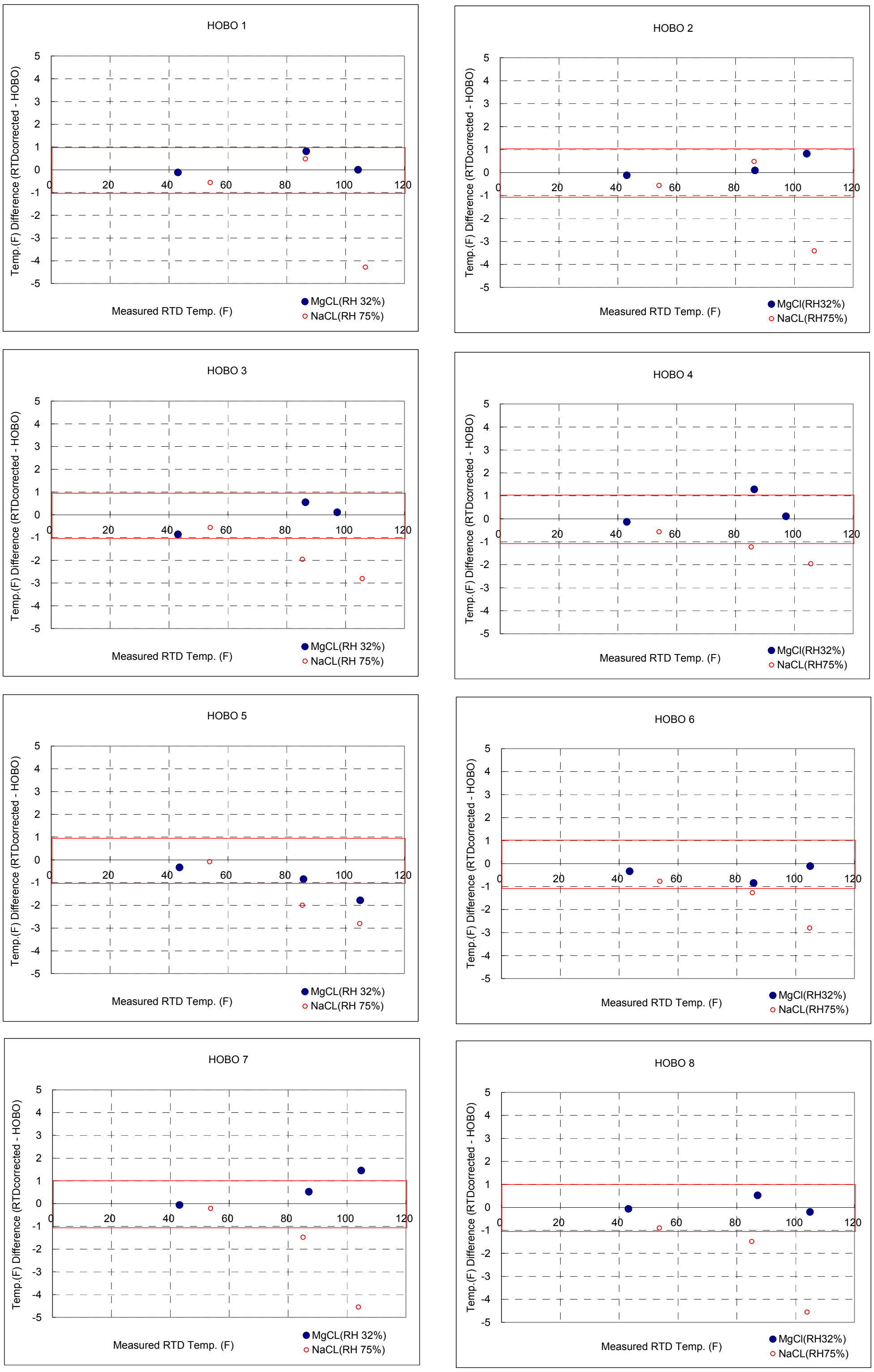


Figure E.2 *Temperature measured in magnesium (RH=32%) and sodium (RH=75%) chloride solution.*

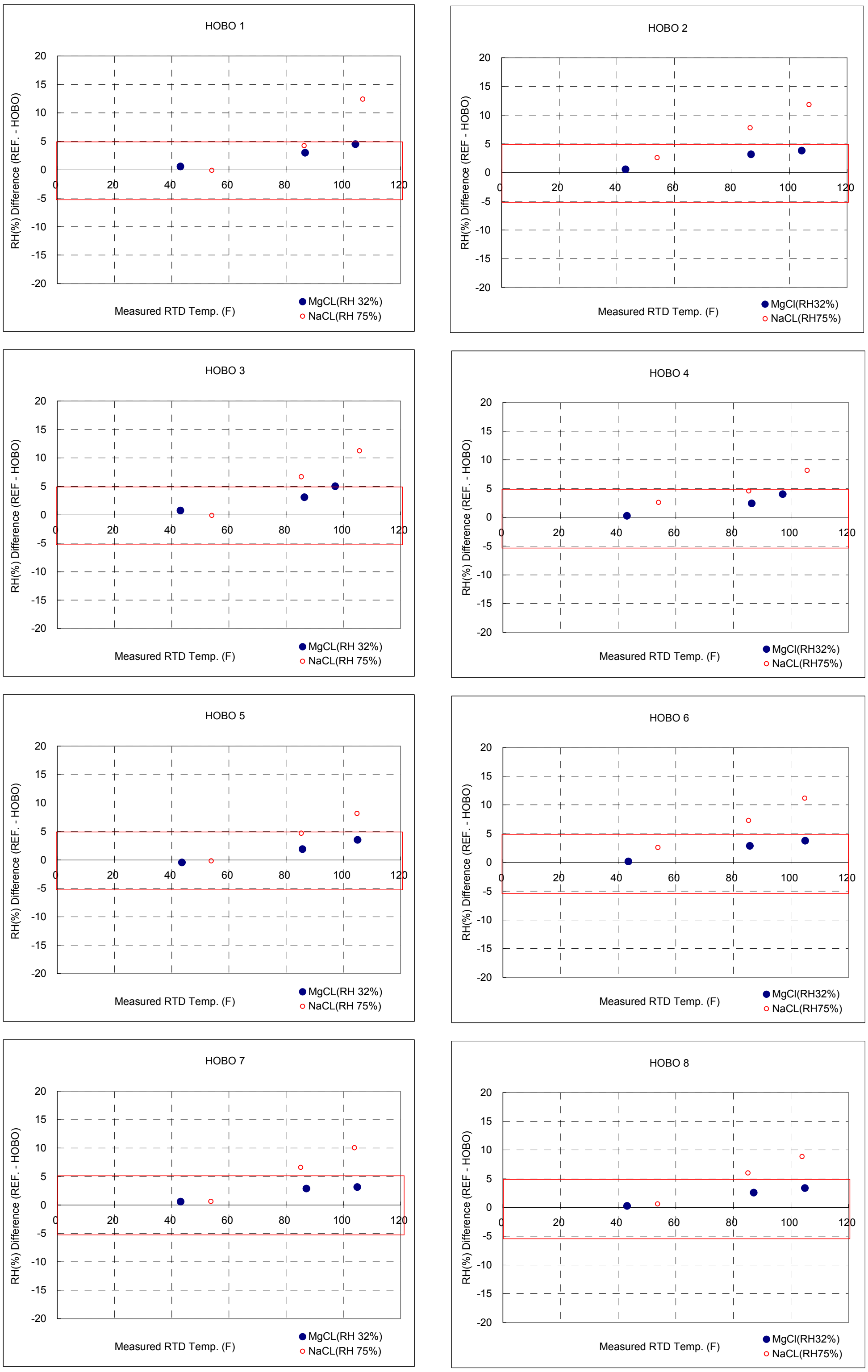
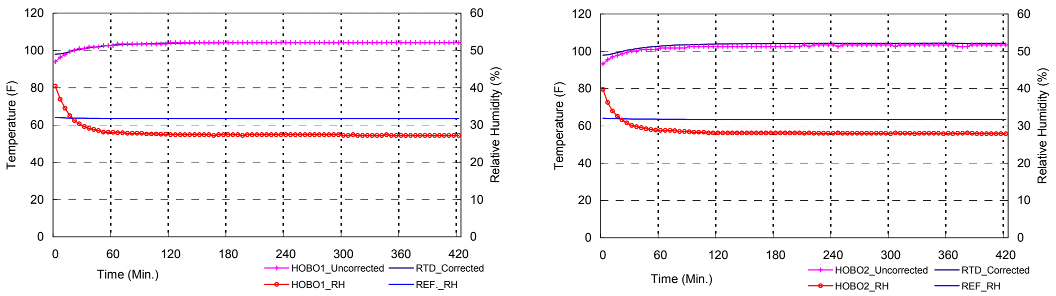
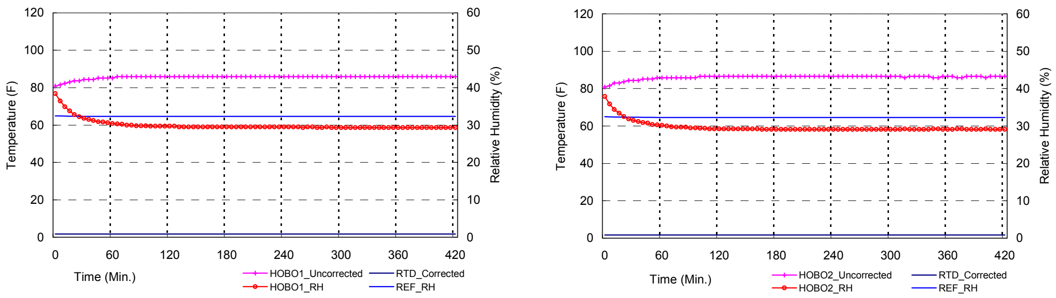


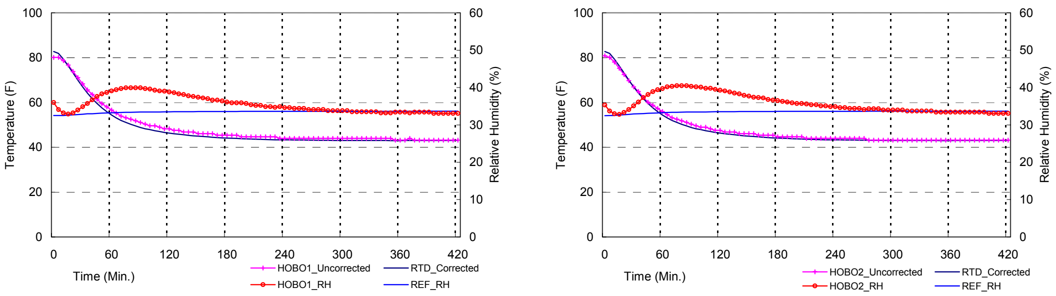
Figure E.3 *RH measured in magnesium (RH=32%) and sodium (RH=75%) chloride solution.*



a) Hot mode

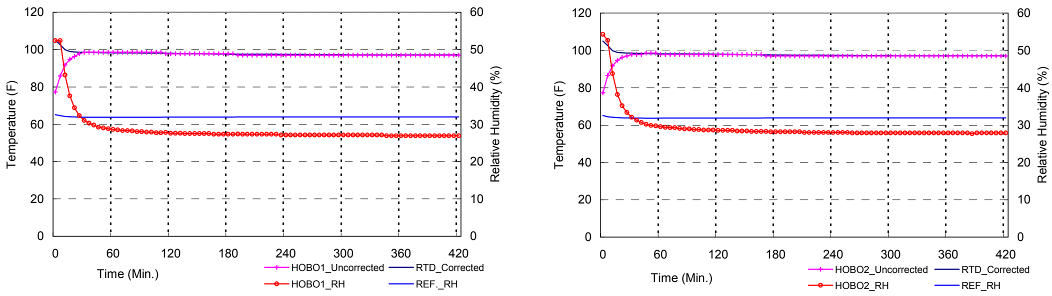


b) Normal mode

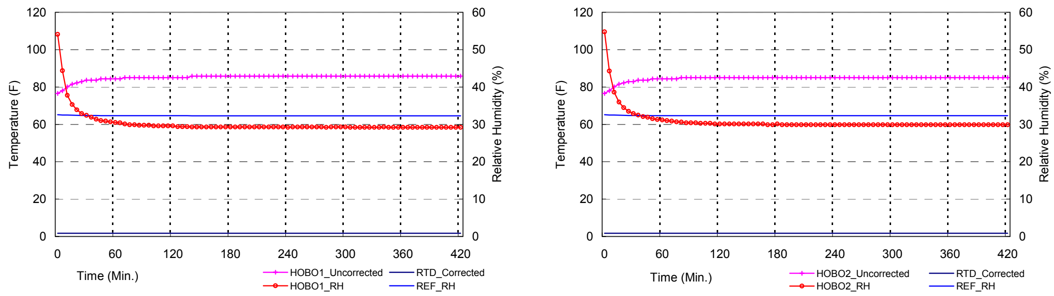


c) Cold mode

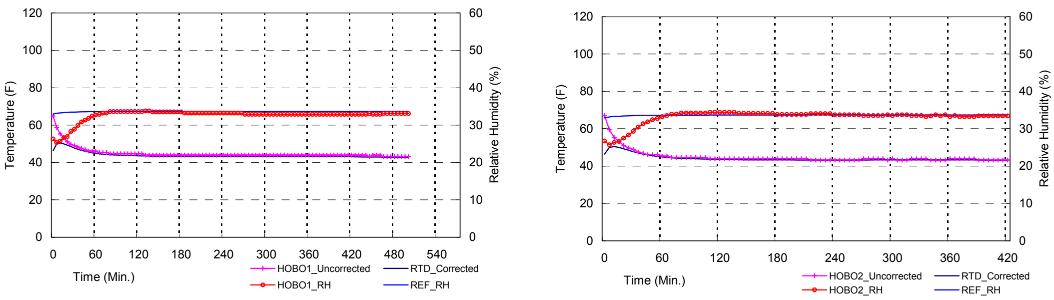
Figure E.4 *Measured data at three temperature mode in magnesium chloride solution (RH=32%) for the portable data logger (HOBO) 1 & 2.*



a) Hot mode

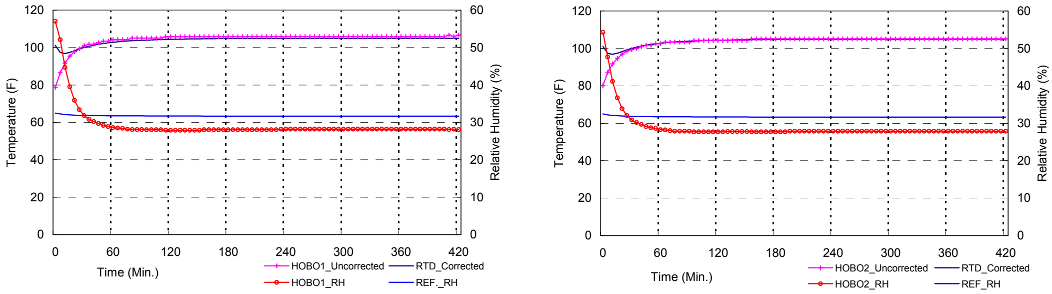


b) Normal mode

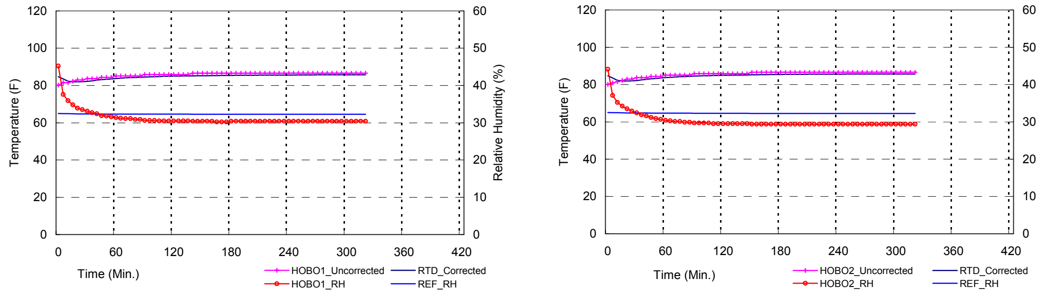


c) Cold mode

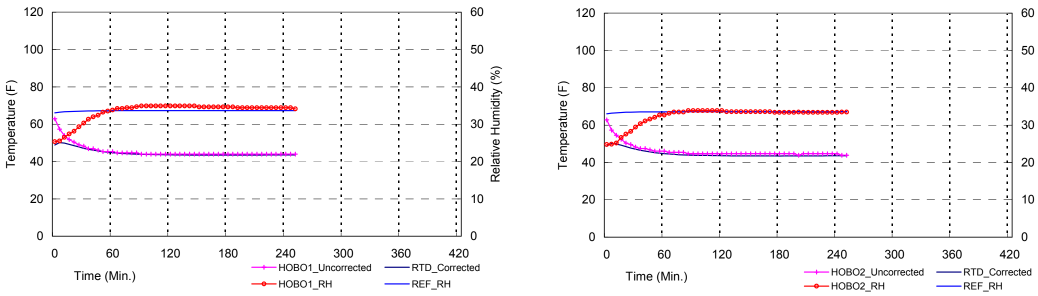
Figure E.5 *Measured data at three temperature mode in magnesium chloride solution (RH=32%) for the portable data logger (HOBO) 3 & 4.*



a) Hot mode

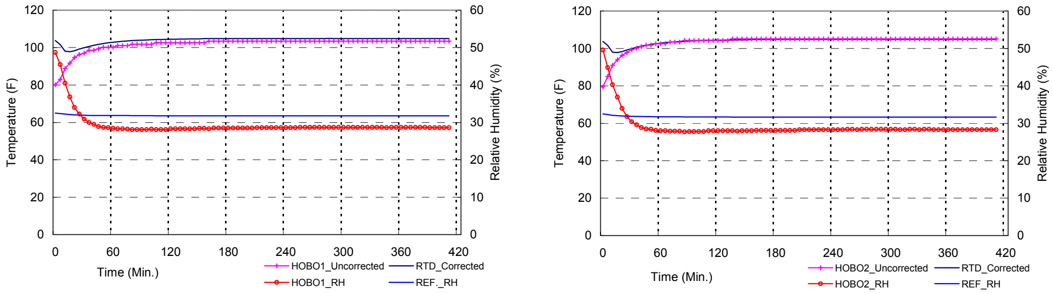


b) Normal mode

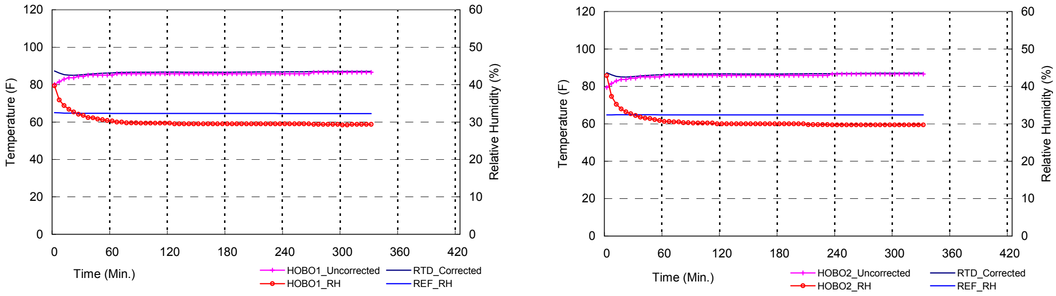


c) Cold mode

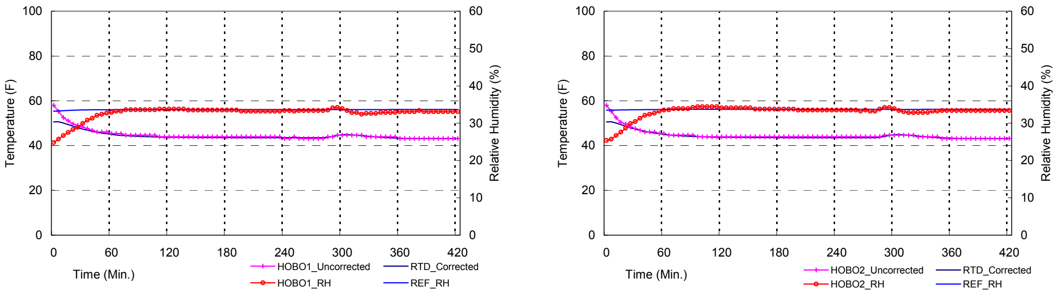
***Figure E.6** Measured data at three temperature mode in magnesium chloride solution (RH=32%) for the portable data logger (HOBO) 5 & 6.*



b) Hot mode

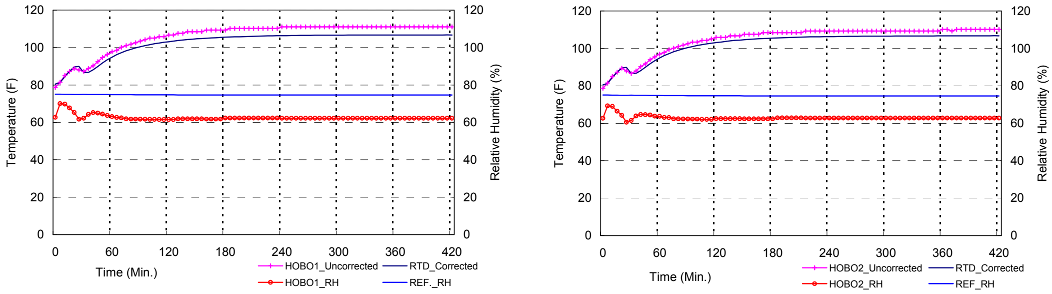


b) Normal mode

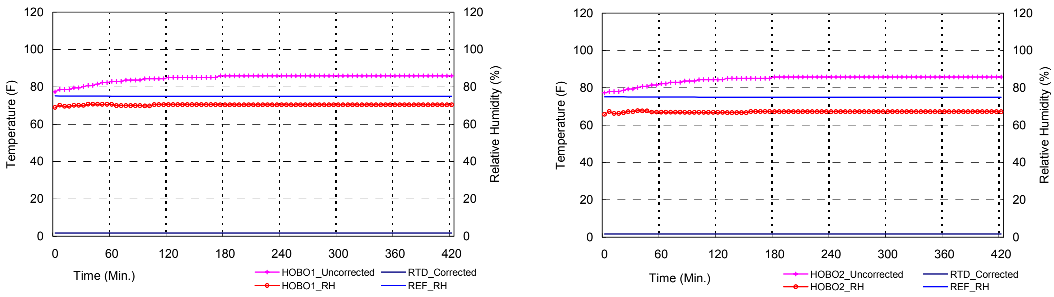


c) Cold mode

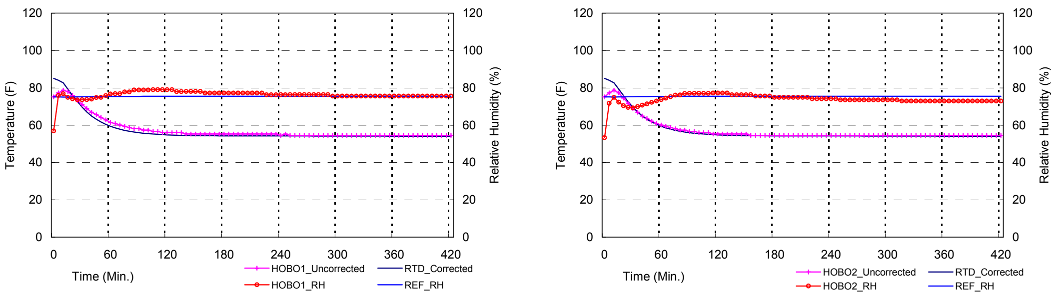
Figure E.7 *Measured data at three temperature mode in magnesium chloride solution (RH=32%) for the portable data logger (HOBO) 7 & 8.*



a) Hot mode

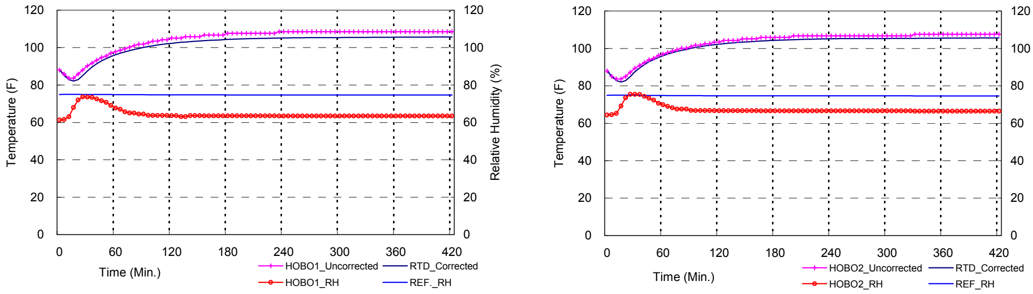


b) Normal Mode

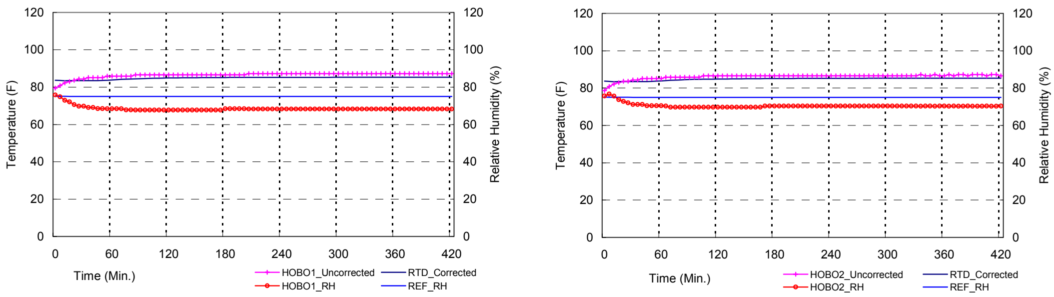


c) Cold Mode

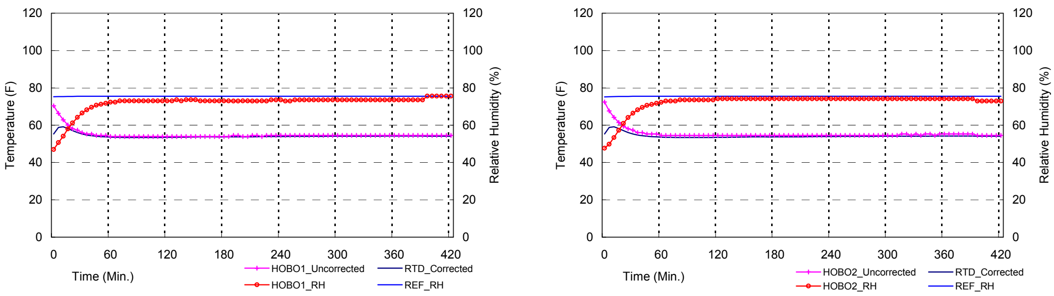
Figure E.8 *Measured data at three temperature mode in sodium chloride solution (RH=75%) for the portable data logger (HOBO) 1 & 2.*



a) Hot mode

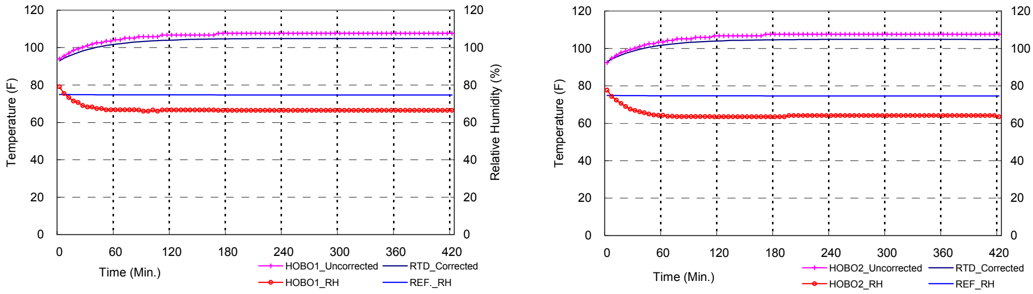


b) Normal mode

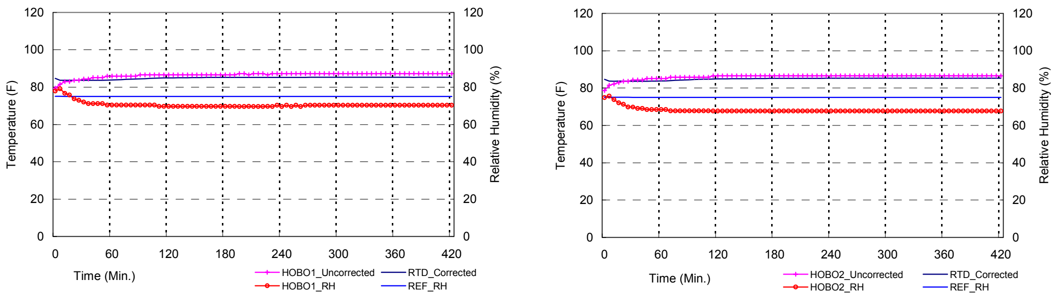


c) Cold mode

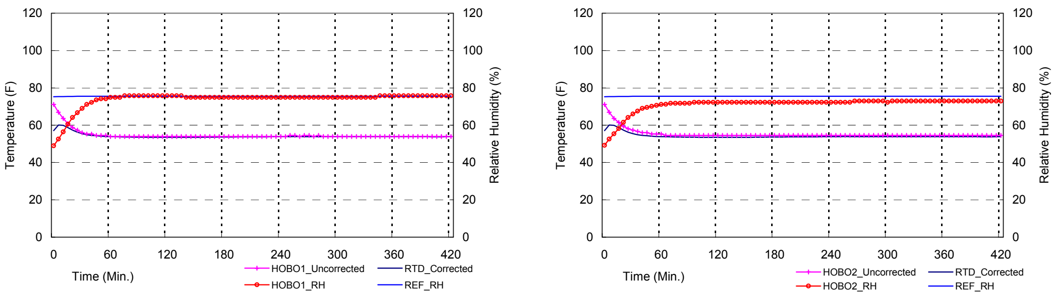
Figure E.9 *Measured Data at three temperature mode in sodium chloride solution (RH=75%) for the portable data logger (HOBO) 3 & 4.*



c) Hot mode

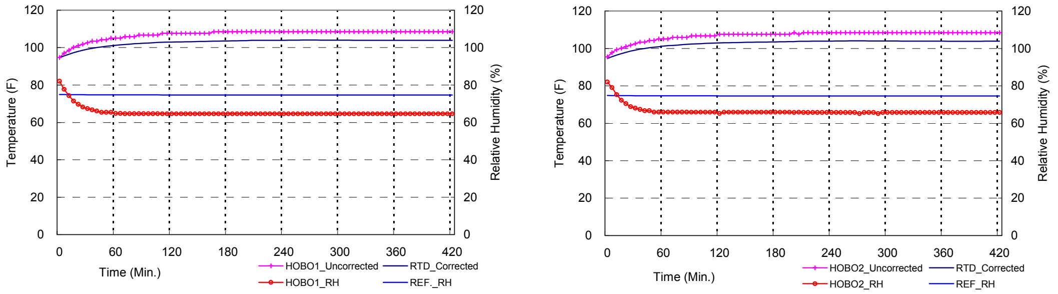


b) Normal mode

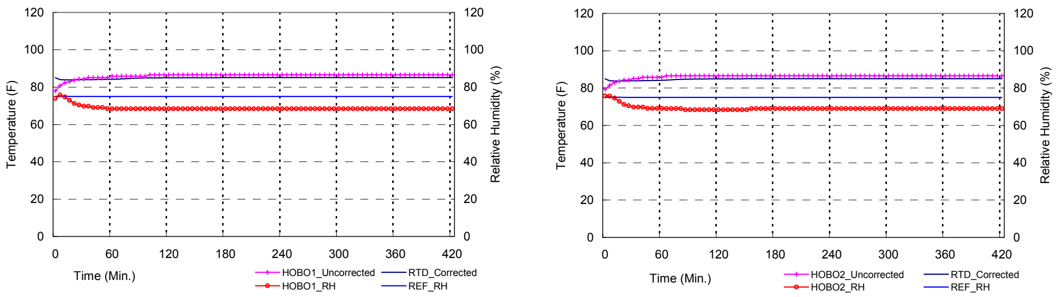


c) Cold mode

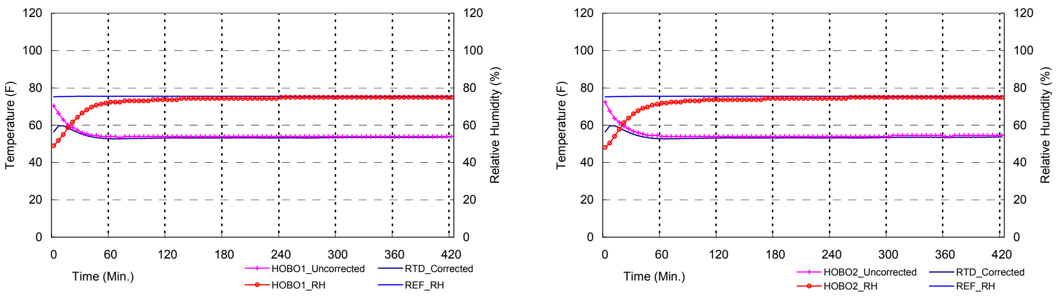
Figure E.10 *Measured data at three temperature mode in sodium chloride solution (RH=75%) for the portable data logger (HOBO) 5 & 6.*



d) Hot mode



b) Normal mode



c) Cold mode

Figure E.11 *Measured data at three temperature mode in sodium chloride solution (RH=75%) for the portable data logger (HOBO) 7 & 8.*

E.2 Eppley PSPs and Li-Cor Sensor Calibration

As discussed in Capter IV, Section 4.4.3.3, the Eppley PSPs and the Li-Cor used in this experiment were calibrated in terms of instrument correction, scale correction, and site-specific correction.

E.2.1. Instrument Correction

Scale correction for the instrument was first performed using both measured PSPs and Li-Cor data from the transmitter to the data logger as shown in Figure E.12. Table E.4 shows the measurement results including the instrument input and the logger output. Figures E.13 to E.16 illustrate the results before and after scale correction for each sensor.

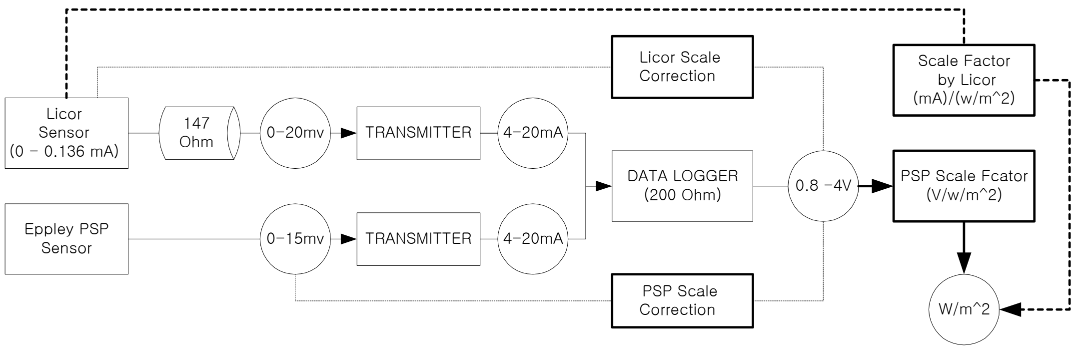


Figure E.12 *Flowchart of the Eppley PSP and Li-Cor instrument scale correction.*

Table E.4 Instrument Input and Logger Output for the Instrument Scale Correction

Sensors	Instrument	Manufacturer	Measured Values		
	Input (mv)	Output (V)	Output (V)	Difference (V)	Corrected (V)
PSP 1	0	0.8	0.784	0.016	0.8
	15	4.0	3.977	0.023	4.0
PSP2	0	0.8	0.773	0.027	0.8
	15	4.0	3.974	0.026	4.0
Li-Cor	0	0.8	0.797	0.003	0.8
	20	4.0	3.987	0.013	4.0

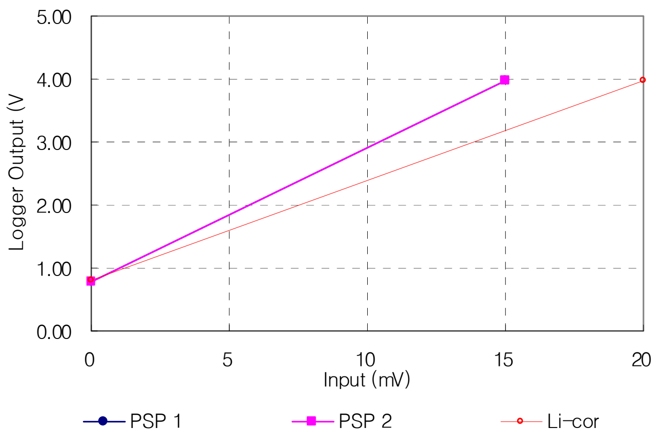


Figure E.13 Logger output vs. instrument input for instrument correction.

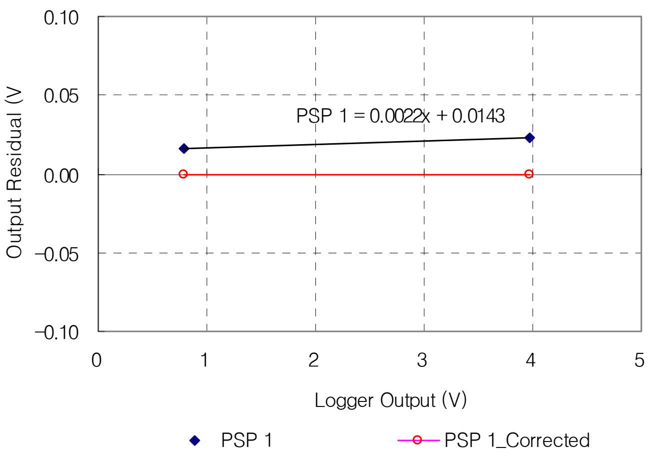


Figure E.14 Output residual vs. logger output for PSP1 instrument correction.

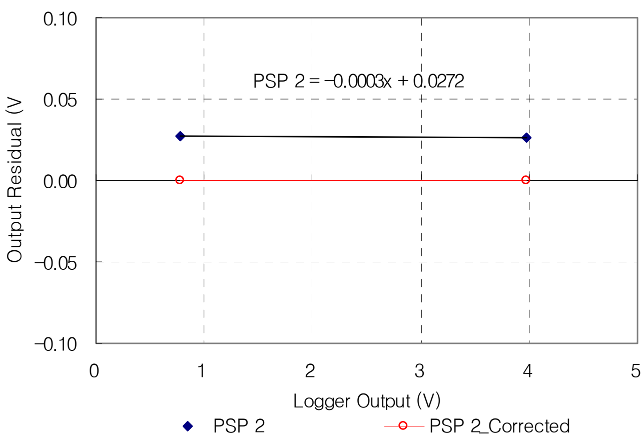


Figure E.15 Output residual vs. logger output for PSP2 instrument correction.

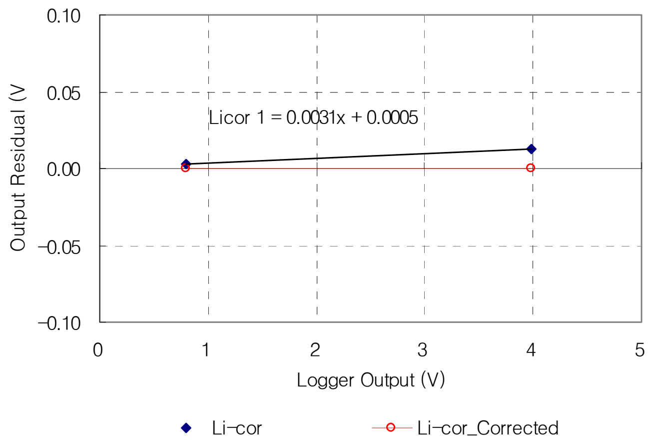


Figure E.16 *Output residual vs. logger output for Li-Cor instrument correction.*

E.2.2. Scale Correction

Prior to the measurement of solar transmittance through sample glazing, the two Eppley PSPs used in this study were compared to the calibrated Eppley PSPs from the National Renewable Energy Laboratory (NREL), and two regression models were then developed for scale correction of each sensor based on the comparison between the logger output (V) from the test PSP and the solar radiation (W/m^2) from the NREL reference PSP, as shown in Figures E.17 and E.18. Figures E.19 and E.20 show the measured solar radiation before and after scale correction. The photovoltaic-type Li-Cor sensor used in this study was also calibrated by the scale correction factor provided by the manufacturer, which is described in Chapter IV, Section 4.4.3.3.

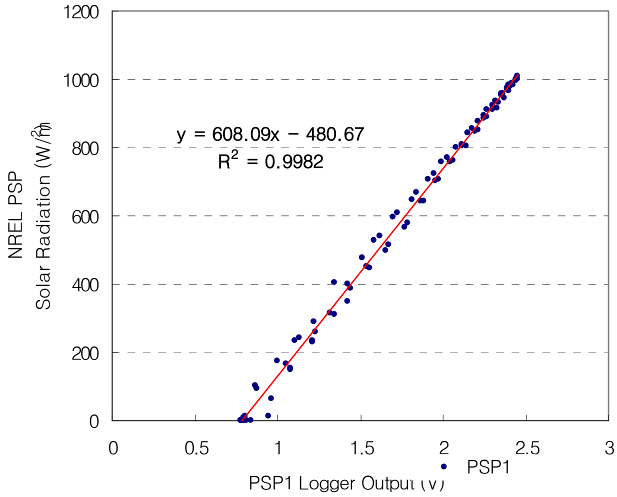


Figure E.17 *PSP1 scale correction against reference (NREL) PSP.*

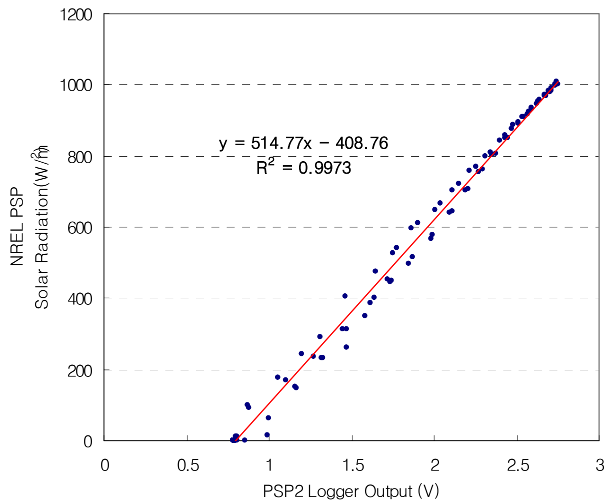


Figure E.18 *PSP1 scale correction against reference (NREL) PSP.*

Figure E.19 *Measured solar radiation before scale correction.*

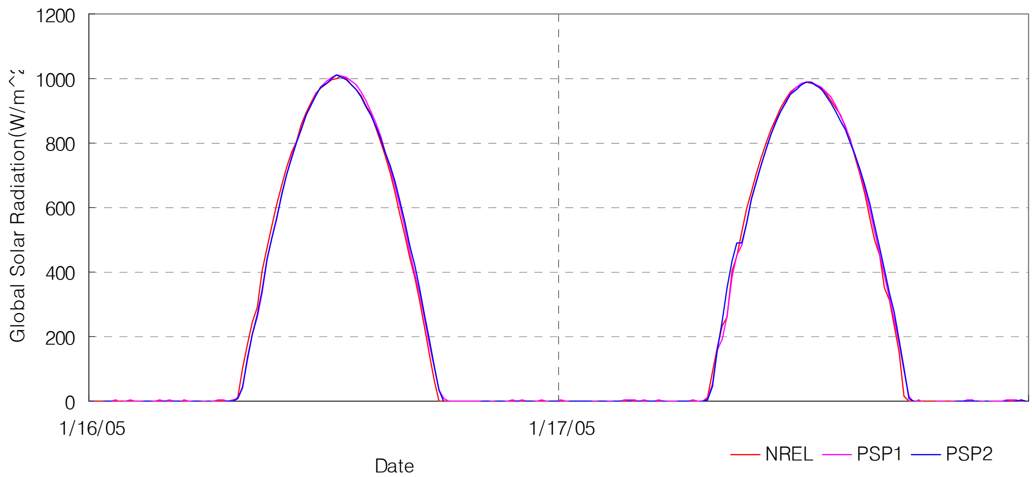


Figure E.20 *Measured solar radiation after scale correction.*

E.2.3. Site-Specific Correction

Site-specifice correction was performed to adjust site deviation, such as sansor location in the solar test bench, before measuring the solar transmittance for the sample glazing. Figures E.21 and E.22 show a comparison of the measured solar radiation between Eppley PSP1 and PSP2 and the residuals before and after scale correction. Figures E.23 and E.24 show a comparison of the measured solar radiation between Eppley PSP1 and Li-Cor and the residuals before and after scale correction. Form the comparisons, linear correction factor (1.0214) with R = 0.9998 was developed for the scale correction between PSP1 and PSP2, while the Li-Cor has a scale (1.0597) and offset (32.046) with R = 0.9998 against PSP1. Finally, post corrections were also performed after the experiment.

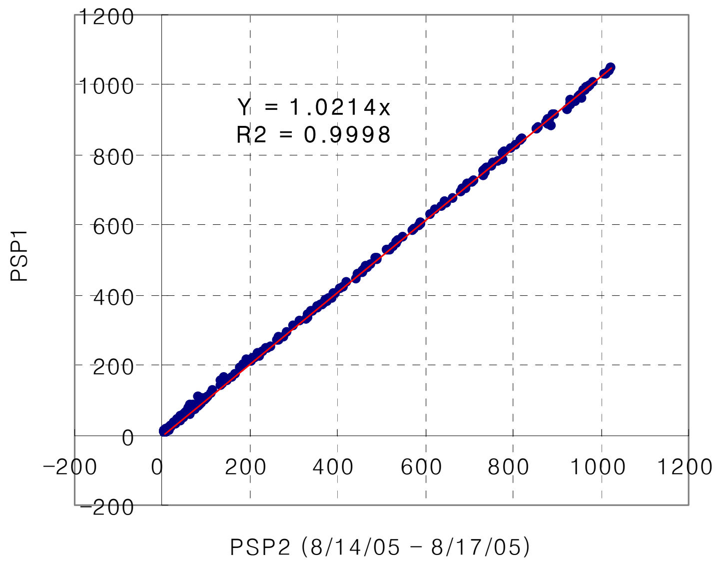


Figure E.21 *Comparison of measured solar radiation between Eppley PSP1 and PSP2.*

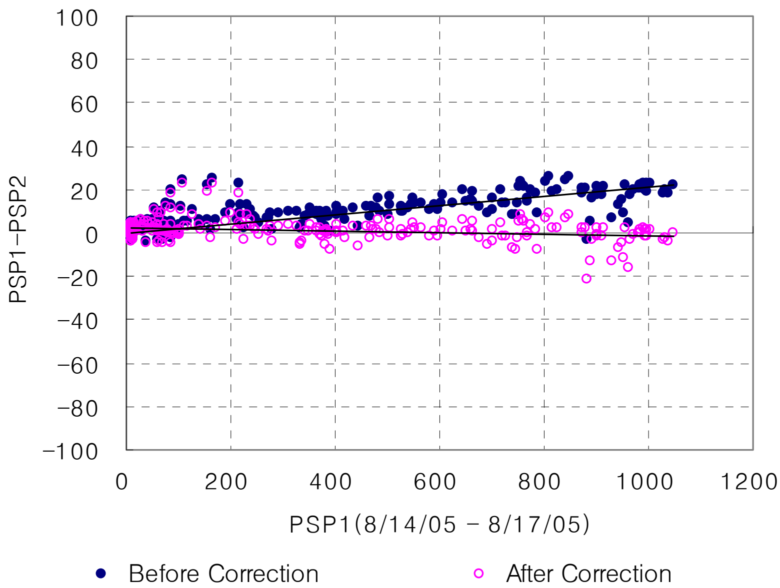


Figure E.22 *Residual (PSP1-PSP2) against PSP1 before and after scale correction.*

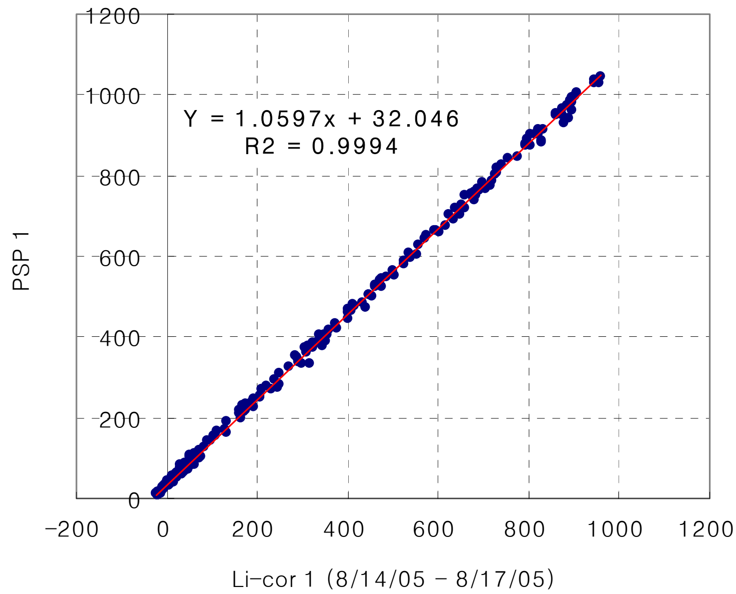


Figure E.23 *Comparison of measured solar radiation between Eppley PSP1 and Li-Cor.*

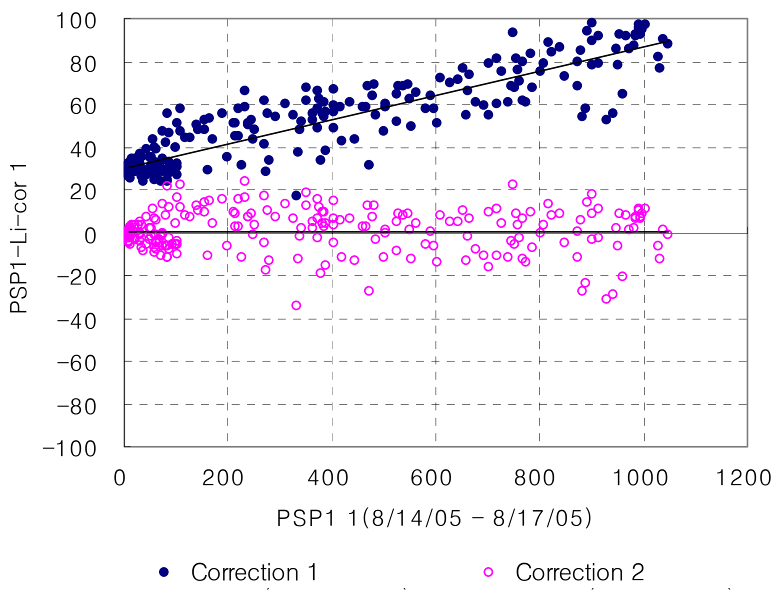


Figure E.24 *Residual (PSP1-Li-Cor) against PSP1 before and after scale correction.*

APPENDIX F

AS-BUILT SIMULATION INPUT FILES

This appendix includes the DOE-2 window libraries generated using Window 5.2 program for the sample glazing used in this study and an example of DOE-2 input file (i.e., 2001 Calibrated As-built model).

F.1 Window Library Files

F.1.1. Low-e glazing (Glazing No: VE1-40#2)

```
Window 5.2a  v5.2.17a  DOE-2 Data File : Multi Band Calculation
Unit System : SI
Name        : DOE-2 WINDOW LIB
Desc        : REJ_Lower
Window ID   : 4010
Tilt        : 90.0
Glazings    : 2
Frame       :  1 Al no break          10.790
Spacer      :  1 Class1                2.330  -0.010   0.138
Total Height: 1500.0 mm
Total Width : 1200.0 mm
Glass Height: 1385.7 mm
Glass Width : 1085.7 mm
Mullion     : None
Gap        Thick    Cond  dCond    Vis   dVis   Dens   dDens     Pr     dPr
1 Air       12.7 0.02407  7.760  1.722  4.940  1.292 -0.0046  0.720 -0.0002
2              0       0      0      0      0      0       0      0       0
3              0       0      0      0      0      0       0      0       0
4              0       0      0      0      0      0       0      0       0
5              0       0      0      0      0      0       0      0       0
Angle     0    10    20    30    40    50    60    70    80    90 Hemis
Tsol  0.207 0.208 0.205 0.201 0.195 0.184 0.160 0.116 0.053 0.000 0.171
Abs1  0.513 0.517 0.522 0.523 0.520 0.516 0.511 0.484 0.362 0.001 0.500
Abs2  0.030 0.030 0.031 0.031 0.032 0.032 0.031 0.026 0.018 0.000 0.029
Abs3      0     0     0     0     0     0     0     0     0     0     0
Abs4      0     0     0     0     0     0     0     0     0     0     0
Abs5      0     0     0     0     0     0     0     0     0     0     0
Abs6      0     0     0     0     0     0     0     0     0     0     0
Rfsol 0.250 0.244 0.242 0.245 0.254 0.269 0.298 0.373 0.567 0.999 0.289
Rbsol 0.221 0.217 0.215 0.216 0.222 0.238 0.277 0.374 0.579 1.000 0.267
Tvis  0.363 0.365 0.360 0.354 0.344 0.326 0.286 0.209 0.098 0.000 0.304
Rfvis 0.153 0.146 0.144 0.147 0.157 0.175 0.210 0.298 0.517 0.999 0.200
Rbvis 0.193 0.187 0.186 0.189 0.201 0.227 0.282 0.409 0.651 1.000 0.262
SHGC  0.277 0.278 0.276 0.272 0.266 0.255 0.230 0.180 0.100 0.000 0.239
SC: 0.35


Layer ID#         6047      103         0        0        0        0
Tir              0.000    0.000         0        0        0        0
Emis F           0.840    0.840         0        0        0        0
Emis B           0.090    0.840         0        0        0        0
Thickness(mm)      5.7      5.7         0        0        0        0
Cond(W/m2-K     )176.7    175.0         0        0        0        0
Spectral File    VE140.VIR  CLEAR_6.DAT         None         None         None         None

Overall and Center of Glass Ig U-values (W/m2-K)
Outdoor Temperature                 -17.8 C      15.6 C      26.7 C      37.8 C
Solar      WdSpd  hcout hrout  hin
(W/m2)      (m/s)     (W/m2-K)
   0        0.00   4.00  3.32  6.87  1.45 1.45  1.45 1.45  1.49 1.49  1.57 1.57
   0        6.71  30.84  3.21  6.94  1.76 1.76  1.67 1.67  1.71 1.71  1.79 1.79
 783        0.00   4.00  4.18  6.95  1.45 1.45  1.45 1.45  1.49 1.49  1.57 1.57
 783        6.71  30.84  3.43  6.61  1.76 1.76  1.67 1.67  1.71 1.71  1.79 1.79
```

F.1.2. Low-e glazing (Glazing No: VE1-2M)

```
Window 5.2  v5.2.17  DOE-2 Data File : Multi Band Calculation

Unit System : SI
Name        : DOE-2 WINDOW LIB
Desc        : REJ-L-Window (Low-e glazing)
Window ID   : 4000
Tilt        : 90.0
Glazings    : 1
Frame       :  1 Al no break          10.790
Spacer      :  1 Class1                2.330  -0.010   0.138
Total Height: 1500.0 mm
Total Width : 1200.0 mm
Glass Height: 1385.7 mm
Glass Width : 1085.7 mm
Mullion     : None
Gap        Thick    Cond  dCond    Vis   dVis   Dens   dDens     Pr     dPr
1              0       0      0      0      0      0       0      0       0
2              0       0      0      0      0      0       0      0       0
3              0       0      0      0      0      0       0      0       0
4              0       0      0      0      0      0       0      0       0
5              0       0      0      0      0      0       0      0       0
Angle     0    10    20    30    40    50    60    70    80    90 Hemis
Tsol  0.253 0.254 0.251 0.247 0.242 0.234 0.215 0.175 0.105 0.000 0.221
Abs1  0.503 0.508 0.513 0.514 0.510 0.504 0.496 0.462 0.337 0.001 0.487
Abs2      0     0     0     0     0     0     0     0     0     0     0
Abs3      0     0     0     0     0     0     0     0     0     0     0
Abs4      0     0     0     0     0     0     0     0     0     0     0
Abs5      0     0     0     0     0     0     0     0     0     0     0
Abs6      0     0     0     0     0     0     0     0     0     0     0
Rfsol 0.244 0.238 0.236 0.239 0.247 0.262 0.290 0.363 0.557 0.999 0.282
Rbsol 0.261 0.255 0.254 0.256 0.265 0.279 0.306 0.377 0.567 0.999 0.298
Tvis  0.406 0.409 0.404 0.398 0.390 0.376 0.345 0.281 0.169 0.000 0.355
Rfvis 0.139 0.132 0.131 0.134 0.143 0.160 0.191 0.275 0.496 0.999 0.184
Rbvis 0.141 0.134 0.133 0.136 0.145 0.162 0.193 0.276 0.497 0.999 0.186
SHGC  0.327 0.329 0.327 0.323 0.318 0.308 0.288 0.242 0.153 0.000 0.292
SC: 0.41


Layer ID#        6047        0        0        0        0        0
Tir             0.000        0        0        0        0        0
Emis F          0.840        0        0        0        0        0
Emis B          0.090        0        0        0        0        0
Thickness(mm)     5.7        0        0        0        0        0
Cond(W/m2-K     )176.7        0        0        0        0        0
Spectral File    VE140.VIR         None         None         None         None         None
Overall and Center of Glass Ig U-values (W/m2-K)
Outdoor Temperature                -17.8 C      15.6 C      26.7 C      37.8 C
Solar      WdSpd  hcout hrout  hin
(W/m2)      (m/s)     (W/m2-K)
   0        0.00    4.00  3.41  2.98  2.32 2.32  1.85 1.85  1.71 1.71  2.21 2.21
   0        6.71   30.84  3.24  3.20  3.23 3.23  2.29 2.29  2.05 2.05  2.75 2.75
 783        0.00    4.00  4.13  2.19  2.32 2.32  1.85 1.85  1.71 1.71  2.21 2.21
 783        6.71   30.84  3.44  2.90  3.23 3.23  2.29 2.29  2.05 2.05  2.75 2.75
```

F.1.3. Single Glazed Clear (Glazing No: Clear-3DAT)

```
Window 5.2a  v5.2.17a  DOE-2 Data File : Multi Band Calculation

Unit System : SI
Name        : DOE-2 WINDOW LIB
Desc        : default
Window ID   : 102
Tilt        : 90.0
Glazings    : 1
Frame       :  1 Al no break          10.790
Spacer      :  1 Class1                2.330  -0.010   0.138
Total Height: 1500.0 mm
Total Width : 1200.0 mm
Glass Height: 1385.7 mm
Glass Width : 1085.7 mm
Mullion     : None
Gap        Thick    Cond  dCond    Vis   dVis   Dens   dDens     Pr     dPr
1              0       0      0      0      0      0       0      0       0
2              0       0      0      0      0      0       0      0       0
3              0       0      0      0      0      0       0      0       0
4              0       0      0      0      0      0       0      0       0
5              0       0      0      0      0      0       0      0       0
Angle     0    10    20    30    40    50    60    70    80    90 Hemis
Tsol  0.834 0.833 0.831 0.827 0.818 0.797 0.749 0.637 0.389 0.000 0.753
Abs1  0.091 0.092 0.094 0.096 0.100 0.104 0.108 0.110 0.105 0.000 0.101
Abs2      0     0     0     0     0     0     0     0     0     0     0
Abs3      0     0     0     0     0     0     0     0     0     0     0
Abs4      0     0     0     0     0     0     0     0     0     0     0
Abs5      0     0     0     0     0     0     0     0     0     0     0
Abs6      0     0     0     0     0     0     0     0     0     0     0
Rfsol 0.075 0.075 0.075 0.077 0.082 0.099 0.143 0.253 0.506 1.000 0.136
Rbsol 0.075 0.075 0.075 0.077 0.082 0.099 0.143 0.253 0.506 1.000 0.136
Tvis  0.899 0.899 0.898 0.896 0.889 0.870 0.822 0.705 0.441 0.000 0.822
Rfvis 0.083 0.083 0.083 0.085 0.091 0.109 0.156 0.272 0.536 1.000 0.148
Rbvis 0.083 0.083 0.083 0.085 0.091 0.109 0.156 0.272 0.536 1.000 0.148
SHGC  0.858 0.858 0.857 0.853 0.844 0.825 0.778 0.667 0.418 0.000 0.780
SC: 0.91



Layer ID#           102         0         0         0         0         0
Tir               0.000         0         0         0         0         0
Emis F            0.840         0         0         0         0         0
Emis B            0.840         0         0         0         0         0
Thickness(mm)       3.0         0         0         0         0         0
Cond(W/m2-K     )328.1         0         0         0         0         0
Spectral File  CLEAR_3.DAT          None          None          None          None          None

Overall and Center of Glass Ig U-values (W/m2-K)
Outdoor Temperature                 -17.8 C      15.6 C      26.7 C      37.8 C
Solar      WdSpd  hcout hrout  hin
(W/m2)     (m/s)      (W/m2-K)
   0        0.00   4.00  3.54  7.16   3.63 3.63   3.67 3.67   3.75 3.75   4.11 4.11
   0        6.71  30.84  3.30  7.26   5.88 5.88   5.51 5.51   5.52 5.52   6.22 6.22
 783        0.00   4.00  3.64  7.08   3.63 3.63   3.67 3.67   3.75 3.75   4.11 4.11
 783        6.71  30.84  3.33  7.25   5.88 5.88   5.51 5.51   5.52 5.52   6.22 6.22
```

F.1.4. Double Glazed Clear (Glazing No: Clear-3DAT)

```
Window 5.2a  v5.2.17a  DOE-2 Data File : Multi Band Calculation

Unit System : SI
Name        : DOE-2 WINDOW LIB
Desc        : default
Window ID   : 2
Tilt        : 90.0
Glazings    : 2
Frame       :  1 Al no break          10.790
Spacer      :  1 Class1                2.330  -0.010   0.138
Total Height: 1500.0 mm
Total Width : 1200.0 mm
Glass Height: 1385.7 mm
Glass Width : 1085.7 mm
Mullion     : None
Gap        Thick    Cond  dCond    Vis   dVis   Dens   dDens     Pr     dPr
1 Air        3.0 0.02407  7.760  1.722  4.940  1.292 -0.0046  0.720 -0.0002
2              0       0      0      0      0      0       0      0       0
3              0       0      0      0      0      0       0      0       0
4              0       0      0      0      0      0       0      0       0
5              0       0      0      0      0      0       0      0       0
Angle     0    10    20    30    40    50    60    70    80    90 Hemis
Tsol  0.703 0.702 0.699 0.692 0.678 0.646 0.577 0.438 0.208 0.000 0.601
Abs1  0.096 0.097 0.099 0.102 0.106 0.112 0.119 0.127 0.130 0.000 0.110
Abs2  0.072 0.073 0.074 0.075 0.077 0.078 0.077 0.070 0.050 0.000 0.073
Abs3      0     0     0     0     0     0     0     0     0     0     0
Abs4      0     0     0     0     0     0     0     0     0     0     0
Abs5      0     0     0     0     0     0     0     0     0     0     0
Abs6      0     0     0     0     0     0     0     0     0     0     0
Rfsol 0.128 0.128 0.128 0.130 0.139 0.164 0.227 0.365 0.612 1.000 0.206
Rbsol 0.128 0.128 0.128 0.130 0.139 0.164 0.227 0.365 0.612 1.000 0.206
Tvis  0.814 0.814 0.813 0.809 0.797 0.766 0.693 0.537 0.273 0.000 0.712
Rfvis 0.150 0.150 0.150 0.153 0.164 0.193 0.264 0.418 0.682 1.000 0.238
Rbvis 0.150 0.150 0.150 0.153 0.164 0.193 0.264 0.418 0.682 1.000 0.238
SHGC  0.757 0.756 0.754 0.749 0.736 0.705 0.638 0.497 0.257 0.000 0.658
SC: 0.82



Layer ID#           102       102         0         0         0         0
Tir               0.000     0.000         0         0         0         0
Emis F            0.840     0.840         0         0         0         0
Emis B            0.840     0.840         0         0         0         0
Thickness(mm)       3.0       3.0         0         0         0         0
Cond(W/m2-K     )328.1     328.1          0         0         0         0
Spectral File  CLEAR_3.DAT  CLEAR_3.DAT          None          None          None          None

Overall and Center of Glass Ig U-values (W/m2-K)
Outdoor Temperature                 -17.8 C      15.6 C      26.7 C      37.8 C
Solar      WdSpd  hcout hrout  hin
(W/m2)     (m/s)     (W/m2-K)
   0        0.00   4.00  3.45  7.08  2.71 2.71  2.80 2.80  2.87 2.87  3.09 3.09
   0        6.71  30.84  3.25  7.17  3.76 3.76  3.74 3.74  3.79 3.79  4.13 4.13
 783        0.00   4.00  3.63  6.80  2.71 2.71  2.80 2.80  2.87 2.87  3.09 3.09
 783        6.71  30.84  3.31  7.10  3.76 3.76  3.74 3.74  3.79 3.79  4.13 4.13
```

D.2 An Example of DOE-2 Input File (i.e., 2001 Calibrated As-built Model)

```
$*************************************************************************************
$       PROGRAM:              DOE-2 SIMULATION INPUT FILE
$
$       LANGUAGE:             DOE-2.1E BDL VERSION 119
$
$       SPONSOR:              TEXAS STATE LEGISLATURE
$
$       PURPOSE:              This input file is a calibrated simulation of
$                              the Robert E. Johnson state office building.
$
$                             To run this file only the parameters need to be changed.
$                             All other variables are referenced to the parameters.
$
$       COPYRIGHT:            TEES, 2006.
$                             This program bears a copyright notice to prevent rights
$                             from being claimed by any other party. This program
$                             shall not be redistributed or sold without written
$                             approval from the Texas Engineering Experiment Station
$                             (TEES).
$
$                             The program is distributed "as is". TEES DOES NOT
$                             WARRANT THAT THE OPERATION OF THE PROGRAM WILL BE
$                             UNINTERRUPTED OR ERROR-FREE, AND MAKES NO
$                             REPRESENTATIONS OR OTHER WARRANTIES, EXPRESS OR IMPLIED,
$                             INCLUDING BUT NOT LIMITED TO THE IMPLIED WARRANTIES
$                             OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.
$
$                             No support service will be provided unless
$                             written arrangements have been made to do so. Certain
$                             manufacturers and trade names are mentioned in this code
$                             for the purpose of describing  their product parameters
$                             Such reference does not constitute an
$                             endorsement or recommendation of such equipment, but is
$                             provided for informational purposes only.
$
$       DEVELOPER:            SUWON SONG
$                             Department of Architecture
$                             Energy Systems Laboratory
$                             Texas A&M University, College Station, TX 77843
$
$                              JEFF HABERL  Ph.D., P.E
$                             Professor
$                             Department of Architecture
$                             Energy Systems Laboratory
$                             Texas A&M University, College Station, TX 77843
$                             PHONE: (979)845-6065,   FAX: (979)862-2457
$                             Email: jhaberl@esl.tamu.edu
$
$
$
$*************************************************************************************


INPUT LOADS  INPUT-UNITS  = ENGLISH          $DOE-2 DEFAULT(OR METRIC)
             OUTPUT-UNITS = ENGLISH ..       $DOE-2 DEFAULT(OR METRIC)

$************************* TITLE ******************************************************

TITLE        LINE-1 *AS-BUILT 5_1: R.E.JOHNSON BLDG., AUSTIN *
             LINE-2 *SUWON SONG, TEXAS A&M UNIVERSITY * ..
```

```
$****************** RUN PERIOD ***********************************************************

RUN-PERIOD         JAN 1 2001 THRU DEC 31 2001    ..

$******************* DIAGNOSTICS *********************************************************

DIAGNOSTIC
         WARNINGS                              $(OR ERRORS,CAUTIONS,DEFAULTS,COMMENTS)
         NO-ECHO                               $DOE-2 DEFAULT= ECHO
         LIMITS                                $DOE-2 DEFAULT(OR NO-LIMITS)
         SINGLE-SPACED  ..                     $DOE-2 DEFAULT(OR DOUBLE-SPACED)

$**** ABORT ******************************************************************************

        ABORT
        ERRORS  ..                                 $DOE-2 DEFAULT(OR WARNINGS,CAUTIONS)


$***************** LOAD REPORTS **********************************************************

LOADS-REPORT
         VERIFICATION = (LV-A,LV-D,LV-I)       $REPORTS TO BE PRINTED
$                       LV-A,                   GENERAL PROJECT AND BUILDING INPUT
$                       LV-D,                   DETAILS OF EXTERIOR SURFACES IN THE PRJ.
$                       LV-H,                   DETAILS OF WINDOWS OCCURING IN THE PRJ.
$                       LV-I,                   DETAILS OF CONSTRUCTIONS OCCURING IN THE PRJ.
               SUMMARY = (LS-D, LS-F)          $REPORTS TO BE PRINTED
$                       LS-D,                   BUILDING MONTHLY LOAD SUMMARY
$                       LS-F,                   BUILDIING MONTHLY LOAD COMPONENTS IN MBTU
..                                             $END OF LOADS REPORT

BUILDING-LOCATION                              $REJ BUILDING IN AUSTIN, TEXAS
    LATITUDE=30.3
    LONGITUDE=97.7
    ALTITUDE=610
    TIME-ZONE=6
    AZ=14.0
    SURF-TEMP-CALC = NO                        $DOE-2 DEFAULT,NEW COMMAND(DOE2.1E VER.207)
    DAYLIGHT-SAVINGS = YES                     $DOE-2 DEFAULT
    HOLIDAY = YES                              $DOE-2 DEFAULT
    ..                                         $END OF BUILDING LOCATION COMMAND

$***************** MATERIALS ******************************************************

$ FICTITIOUS LAYER
  FIT-1=  MATERIAL  RESISTANCE = 17.94  ..           $BASEMENT WALL
  FIT-2=  MATERIAL  RESISTANCE = 1000   ..           $BASEMENT SLAB(Pexp=0)

$ EARTH SOIL
  M-SOL=  MATERIAL                                   $DOE2 USER NEWS BY FRED WINKELMANN
           THICKNESS= 1                              $(FT)
           CONDUCTIVITY= 1                           $(BTU.FT/HR.FT^2.F)
           DENSITY= 115                              $(LB/FT^3)
           SPECIFIC-HEAT= .1   ..                    $(BTU/LB.F)
$ METAL FRAME
  WMF00=  MATERIAL  RESISTANCE =  .61 ..
  WMF11=  MATERIAL  RESISTANCE = 6 ..                $CONFERENCE CENTER
```

```
$*************** LAYER OF CONSTRUCTION *************************************************

  ROO-1  =LAYERS =MAT=(BR01,IN03,CC26)
          INSIDE-FILM-RES= .61   ..                    $DOE-2 DEFAULT(HR.FT^2.F/BTU)
  ROO-2  =LAYERS =MAT=(WMF11,IN02)
          INSIDE-FILM-RES= .61   ..                    $DOE-2 DEFAULT(HR.FT^2.F/BTU)
  EW-1   =LAYERS =MAT=(CC26,IN02,WMF00,GP02)
          INSIDE-FILM-RES= 1.35  ..                    $DOE-2 DEFAULT(HR.FT^2.F/BTU)
  EW-2   =LAYERS =MAT=(WMF11,IN11)
          INSIDE-FILM-RES= 0.92  ..                    $DOE-2 DEFAULT(HR.FT^2.F/BTU)
  IW-1   =LAYERS =MAT=(GP02, WMF00, GP02)
          INSIDE-FILM-RES= .68   ..                    $DOE-2 DEFAULT(HR.FT^2.F/BTU)
  IF-1   =LAYERS =MAT=(CC36)
          INSIDE-FILM-RES= .68   ..                    $DOE-2 DEFAULT(HR.FT^2.F/BTU)
  UW-1   =LAYERS =MAT=(FIT-1,M-SOL,CC07,IN02,GP02)
          INSIDE-FILM-RES= .92   ..                    $DOE-2 DEFAULT(HR.FT^2.F/BTU)
  UF-1   =LAYERS =MAT=(FIT-2,M-SOL,CC07)
          INSIDE-FILM-RES= .92   ..                    $DOE-2 DEFAULT(HR.FT^2.F/BTU)
  CL-1   =LAYERS =MAT=(GP02)
          INSIDE-FILM-RES= .61   ..                    $DOE-2 DEFAULT(HR.FT^2.F/BTU)

$****************** CONSTRUCTION ***********************************************************

ROOF-1      =CONSTRUCTION    LAYERS =ROO-1          $ TYPICAL ROOF
                             ABSORPTANCE = 0.5 ..   $ DOE-2 DEFAULT =0.7
ROOF-2      =CONSTRUCTION    LAYERS =ROO-2  ..      $ MEETING ROOM ROOF
WALL-1      =CONSTRUCTION    LAYERS =EW-1   ..      $ TYPICAL EXTERIOR-WALL
WALL-1-2    =CONSTRUCTION    LAYERS =EW-2   ..      $ MEETING ROOM EXTERIOR-WALL
WALL-2      =CONSTRUCTION    LAYERS =IW-1   ..      $ INTERIOR-WALL
FLOOR-1     =CONSTRUCTION    LAYERS =IF-1   ..      $ INTERIOR-FLOOR
WALL-U      =CONSTRUCTION    LAYERS =UW-1   ..      $ UNDERGROUND-WALL
FLOOR-U     =CONSTRUCTION    LAYERS =UF-1   ..      $ UNDERGROUND-FLOOR
CLING-1     =CONSTRUCTION    LAYERS =CL-1   ..      $ CEILING

$**************** GLASS TYPES ***********************************************************

W-4000     =GLASS-TYPE
            GLASS-TYPE-CODE = 4020    ..     $LOW-E WINDOW (LOWER PART) FROM WINDOW 5.2

W-5000     =GLASS-TYPE
            GLASS-TYPE-CODE = 4021   ..      $ LOW-E WINDOW (UPPER PART) FROM WINDOW 5.2
$******************** BUILDING SCHEDULES ************************************************

$ OCCUPANCY SCHEDULE
  OCCUPY-1  =SCHEDULE   THRU DEC 31
  (WD)     (1) (0.52) (2)(0.44)  (3)(0.25)  (4)(0.20)  (5)(0.20)  (6)(0.20)
           (7) (0.20) (8)(0.32)  (9)(0.71)  (10)(0.86) (11)(0.93) (12)(0.94)
           (13)(0.94) (14)(0.93) (15)(0.93) (16)(0.93) (17)(0.92) (18)(0.89)
           (19)(0.79) (20)(0.73) (21)(0.68) (22)(0.64) (23)(0.59) (24)(0.56)
  (WEH)    (1)(0.46)  (2)(0.34)  (3)(0.25)  (4)(0.21)  (5)(0.21)  (6)(0.21)
           (7)(0.21)  (8)(0.21)  (9)(0.21)  (10)(0.22) (11)(0.23) (12)(0.25)
           (13)(0.25) (14)(0.26) (15)(0.26) (16)(0.28) (17)(0.27) (18)(0.30)
           (19)(0.30) (20)(0.29) (21)(0.28) (22)(0.29) (23)(0.28) (24)(0.27) ..

$ LIGHTING SCHEDULE
 LIGHT-1   =SCHEDULE  THRU DEC 31
  (WD)     (1) (0.58) (2)(0.55)  (3)(0.52)  (4)(0.51)  (5)(0.51)  (6)(0.51)
           (7) (0.52) (8)(0.55)  (9)(0.65)  (10)(0.74) (11)(0.77) (12)(0.77)
```

```
         (13)(0.78)  (14)(0.77)  (15)(0.78)  (16)(0.78)  (17)(0.77)  (18)(0.75)
         (19)(0.70)  (20)(0.65)  (21)(0.63)  (22)(0.62)  (23)(0.60)  (24)(0.59)
 (WEH)   (1)(0.55)   (2)(0.53)   (3)(0.51)   (4)(0.51)   (5)(0.51)   (6)(0.51)
         (7)(0.51)   (8)(0.51)   (9)(0.50)   (10)(0.49)  (11)(0.49)  (12)(0.50)
         (13)(0.50)  (14)(0.51)  (15)(0.51)  (16)(0.51)  (17)(0.51)  (18)(0.50)
         (19)(0.52)  (20)(0.53)  (21)(0.53)  (22)(0.52)  (23)(0.52)  (24)(0.52) ..

 LIGHT-2  = SCHEDULE   THRU DEC 31 (ALL) (1,24)(1)  ..

$ EQUIPMENT SCHEDULE

 EQUIP-1  = SCHEDULE   THRU DEC 31
 (WD)    (1) (0.58)  (2)(0.55)   (3)(0.52)   (4)(0.51)   (5)(0.51)   (6)(0.51)
         (7) (0.52)  (8)(0.55)   (9)(0.65)   (10)(0.74)  (11)(0.77)  (12)(0.77)
         (13)(0.78)  (14)(0.77)  (15)(0.78)  (16)(0.78)  (17)(0.77)  (18)(0.75)
         (19)(0.70)  (20)(0.65)  (21)(0.63)  (22)(0.62)  (23)(0.60)  (24)(0.59)
 (WEH)   (1)(0.55)   (2)(0.53)   (3)(0.51)   (4)(0.51)   (5)(0.51)   (6)(0.51)
         (7)(0.51)   (8)(0.51)   (9)(0.50)   (10)(0.49)  (11)(0.49)  (12)(0.50)
         (13)(0.50)  (14)(0.51)  (15)(0.51)  (16)(0.51)  (17)(0.51)  (18)(0.50)
         (19)(0.52)  (20)(0.53)  (21)(0.53)  (22)(0.52)  (23)(0.52)  (24)(0.52) ..

 EQUIP-2  =SCHEDULE
           THRU DEC 31 (ALL) (1,24)(1)  ..

 EQUIP-S  = SCHEDULE  THRU DEC 31
(WD)     (1) (0.23)   (2)(0.18)   (3)(0.18)   (4)(0.17)   (5)(0.17)   (6)(0.17)
         (7) (0.18)   (8)(0.21)   (9)(0.39)  (10)(0.61)  (11)(0.64)  (12)(0.64)
         (13)(0.59)  (14)(0.54)  (15)(0.62)  (16)(0.61)  (17)(0.57)  (18)(0.50)
         (19)(0.46)  (20)(0.45)  (21)(0.38)  (22)(0.35)  (23)(0.34)  (24)(0.33)
(WEH)    (1) (0.18)   (2)(0.17)   (3)(0.17)   (4)(0.16)   (5)(0.17)   (6)(0.17)
         (7) (0.16)   (8)(0.16)   (9)(0.16)  (10)(0.17)  (11)(0.16)  (12)(0.18)
         (13)(0.17)  (14)(0.17)  (15)(0.17)  (16)(0.17)  (17)(0.17)  (18)(0.17)
         (19)(0.17)  (20)(0.17)  (21)(0.17)  (22)(0.17)  (23)(0.16)  (24)(0.16) ..

 EQUIP-T  = SCHEDULE  THRU DEC 31
(WD)     (1) (0.31)   (2)(0.26)   (3)(0.25)   (4)(0.24)   (5)(0.23)   (6)(0.23)
         (7) (0.24)   (8)(0.32)   (9)(0.50)  (10)(0.63)  (11)(0.67)  (12)(0.66)
         (13)(0.64)  (14)(0.61)  (15)(0.64)  (16)(0.65)  (17)(0.64)  (18)(0.60)
         (19)(0.54)  (20)(0.50)  (21)(0.44)  (22)(0.39)  (23)(0.37)  (24)(0.37)
(WEH)    (1) (0.26)   (2)(0.24)   (3)(0.23)   (4)(0.22)   (5)(0.22)   (6)(0.23)
         (7) (0.22)   (8)(0.22)   (9)(0.21)  (10)(0.20)  (11)(0.20)  (12)(0.20)
         (13)(0.20)  (14)(0.20)  (15)(0.20)  (16)(0.21)  (17)(0.20)  (18)(0.20)
         (19)(0.20)  (20)(0.21)  (21)(0.21)  (22)(0.22)  (23)(0.22)  (24)(0.22) ..

EQUIP-C  = SCHEDULE  THRU DEC 31
(WD)     (1) (0.46)  (2)(0.45)   (3)(0.45)   (4)(0.44)   (5)(0.44)   (6)(0.43)
         (7) (0.44)  (8)(0.44)   (9)(0.39)   (10)(0.35)  (11)(0.36)  (12)(0.36)
         (13)(0.32)  (14)(0.31)  (15)(0.34)  (16)(0.34)  (17)(0.33)  (18)(0.32)
         (19)(0.35)  (20)(0.51)  (21)(0.45)  (22)(0.47)  (23)(0.49)  (24)(0.50)
(WEH)    (1) (0.46)  (2)(0.46)   (3)(0.44)   (4)(0.46)   (5)(0.44)   (6)(0.45)
         (7) (0.43)  (8)(0.44)   (9)(0.33)   (10)(0.25)  (11)(0.22)  (12)(0.22)
         (13)(0.22)  (14)(0.21)  (15)(0.21)  (16)(0.20)  (17)(0.21)  (18)(0.21)
         (19)(0.28)  (20)(0.32)  (21)(0.36)  (22)(0.41)  (23)(0.42)  (24)(0.41) ..

$ INFILTRATION SCHEDULE
 INFIL-SCH   =SCHEDULE
              THRU DEC 31 (ALL) (1,24) (0)  ..     $ HVAC ON (AIR-CHANGES/HR=0)
```

```
$ SHADING SCHEDULE
  SHADE-SCH1  =SCHEDULE             $FOR TREES
              THRU APR 30 (ALL) (1,24) (0.2)       $ WINTER & SPRING
              THRU SEP 30 (ALL) (1,24) (0.5)       $ SUMMER
              THRU DEC 31 (ALL) (1,24) (0.3)  ..   $ FALL & WINTER

  SHADE-SCH2= SCHEDULE             $FOR BUILDING
              THRU DEC 31 (ALL) (1,24) (1)   ..

  SHADE-SCH3= SCHEDULE             $FOR WINDOW DUE TO BLIENDS
              THRU APR 30 (ALL) (1,24) (1)
              THRU SEP 30 (ALL) (1,24) (1)
              THRU DEC 31 (ALL) (1,24) (1) ..

$  DAYLIGHT TRANSMITTANCE SCHEDULE
  TVIS-SCH1   =SCHEDULE             $ DUE TO WINDOW BLIENDS
              THRU DEC 31 (ALL) (1,24) (0.7)  ..

$ SET DEFAULT VALUES
  SET-DEFAULT FOR SPACE              FLOOR-WEIGHT= 0       ..
  SET-DEFAULT FOR EXTERIOR-WALL      CONSTRUCTION= WALL-1
                                     SHADING-SURFACE= YES   ..
  SET-DEFAULT FOR INTERIOR-WALL      CONSTRUCTION= WALL-2   ..
  SET-DEFAULT FOR ROOF               CONSTRUCTION= ROOF-1   ..
  SET-DEFAULT FOR UNDERGROUND-WALL   CONSTRUCTION= WALL-U
                                     U-EFFECTIVE = 0.048 ..
  SET-DEFAULT FOR UNDERGROUND-FLOOR  CONSTRUCTION= FLOOR-U
                                     U-EFFECTIVE = 0.001 ..
  SET-DEFAULT FOR WINDOW             Y=2.33
                                     WIN-SHADE-TYPE= MOVABLE-INTERIOR
                                     VIS-TRANS-SCH= TVIS-SCH1
                                     SHADING-SCHEDULE= SHADE-SCH3
                                     ..
$ ***************** BUILDING SHADE *************************************************

$ FOR THE ADJUSCENT BUILDINGS

BSHADE1-1   BUILDING-SHADE
            X=200  Y=450  Z=0 H=120 W=240 AZ=180
            TRANSMITTANCE  = 0
            SHADE-SCHEDULE = SHADE-SCH2
            ..
BSHADE1-2   BUILDING-SHADE LIKE BSHADE1-1
            X=440 Y=450 Z=0 H=120 W=120 AZ=90   ..
BSHADE1-3   BUILDING-SHADE LIKE BSHADE1-1
            X=440 Y=570 Z=0 H=120 W=240 AZ=0    ..
BSHADE1-4   BUILDING-SHADE LIKE BSHADE1-1
            X=200 Y=570 Z=0 H=120 W=120 AZ=270  ..
BSHADE2-1   BUILDING-SHADE LIKE BSHADE1-1
            X=540 Y=300 Z=0 H=70 W=140 AZ=180   ..
BSHADE2-2   BUILDING-SHADE LIKE BSHADE1-1
            X=680 Y=300 Z=0 H=70 W=300 AZ=90    ..
BSHADE2-3   BUILDING-SHADE LIKE BSHADE1-1
            X=680 Y=600 Z=0 H=70 W=140 AZ=0     ..
BSHADE2-4   BUILDING-SHADE LIKE BSHADE1-1
            X=540 Y=600 Z=0 H=70 W=300 AZ=270   ..

$ FOR THE TREES IN FRONT OF THE BUILDING
```

```
TSHADE1-1   BUILDING-SHADE TILT=0  X=60 Y=30 Z=32 H=20 W=20
            SHADE-SCHEDULE= SHADE-SCH1 ..
TSHADE1-2   BUILDING-SHADE LIKE TSHADE1-1 Z=39 H=20 W=20 ..
TSHADE1-3   BUILDING-SHADE LIKE TSHADE1-1 Z=46 H=25 W=25 ..
TSHADE1-4   BUILDING-SHADE LIKE TSHADE1-1 Z=53 H=30 W=30 ..
TSHADE1-5   BUILDING-SHADE LIKE TSHADE1-1 Z=60 H=28 W=28 ..
TSHADE1-6   BUILDING-SHADE LIKE TSHADE1-1 Z=67 H=25 W=25 ..
TSHADE1-7   BUILDING-SHADE LIKE TSHADE1-1 Z=74 H=23 W=23 ..

TSHADE2-1   BUILDING-SHADE TILT=0  X=190 Y=20 Z=10 H=20 W=35
            SHADE-SCHEDULE= SHADE-SCH1 ..
TSHADE2-2   BUILDING-SHADE LIKE TSHADE2-1 Z=17 H=50 W=30 ..
TSHADE2-3   BUILDING-SHADE LIKE TSHADE2-1 Z=24 H=48 W=28 ..
TSHADE2-4   BUILDING-SHADE LIKE TSHADE2-1 Z=30 H=45 W=25 ..
TSHADE2-5   BUILDING-SHADE LIKE TSHADE2-1 Z=37 H=35 W=22 ..
TSHADE2-6   BUILDING-SHADE LIKE TSHADE2-1 Z=44 H=30 W=20 ..
TSHADE2-7   BUILDING-SHADE LIKE TSHADE2-1 Z=51 H=20 W=18 ..

TSHADE3-1   BUILDING-SHADE TILT=0 X=265  Y=-10  Z=17 H=30 W=40
            SHADE-SCHEDULE= SHADE-SCH1 ..
TSHADE3-2   BUILDING-SHADE LIKE TSHADE3-1 X=272 Z=24 H=26 W=48 ..
TSHADE3-3   BUILDING-SHADE LIKE TSHADE3-1 X=275 Z=30 H=34 W=55 ..
TSHADE3-4   BUILDING-SHADE LIKE TSHADE3-1 X=280 Z=37 H=40 W=65 ..
TSHADE3-5   BUILDING-SHADE LIKE TSHADE3-1 X=275 Z=44 H=34 W=55 ..
TSHADE3-6   BUILDING-SHADE LIKE TSHADE3-1 X=272 Z=51 H=26 W=48 ..
TSHADE3-7   BUILDING-SHADE LIKE TSHADE3-1 X=270 Z=58 H=22 W=40 ..
TSHADE3-8   BUILDING-SHADE LIKE TSHADE3-1 X=270 Z=65 H=22 W=40 ..

TSHADE4-1   BUILDING-SHADE TILT=0 X=330 Y=-10 Z=17 H=28 W=40
            SHADE-SCHEDULE= SHADE-SCH1 ..
TSHADE4-2   BUILDING-SHADE LIKE TSHADE4-1 X=330 Z=24 H=40 W=35 ..
TSHADE4-3   BUILDING-SHADE LIKE TSHADE4-1 X=328 Z=30 H=35 W=32 ..
TSHADE4-4   BUILDING-SHADE LIKE TSHADE4-1 X=325 Z=37 H=25 W=25 ..
TSHADE4-5   BUILDING-SHADE LIKE TSHADE4-1 X=325 Z=44 H=22 W=25 ..

TSHADE5-1   BUILDING-SHADE TILT=0 X=440 Y=-10 Z=12 H=28 W=40
            SHADE-SCHEDULE= SHADE-SCH1 ..
TSHADE5-2   BUILDING-SHADE LIKE TSHADE5-1 X=440 Z=18 H=26 W=40 ..
TSHADE5-3   BUILDING-SHADE LIKE TSHADE5-1 X=435 Z=25 H=24 W=30 ..
TSHADE5-4   BUILDING-SHADE LIKE TSHADE5-1 X=430 Z=32 H=22 W=20 ..

$***************** GENERAL SPACE DEFINITION ********************************************

OFFICE = SPACE-CONDITIONS
           ZONE-TYPE            =CONDITIONED    $DOE-2 DEFAULT VALUE
           PEOPLE-SCHEDULE      =OCCUPY-1
           AREA/PERSON          =275
           PEOPLE-HG-SENS       =230            $(BTU/HR), DOE-2 DEFAULT = 0
           PEOPLE-HG-LAT        =190            $(BTU/HR), DOE-2 DEFAULT = 0
           LIGHTING-SCHEDULE    =LIGHT-1
           LIGHTING-TYPE        =SUS-FLUOR      $DOE-2 DEFAULT(OR REC-FLOUR-RV,
$                                                REC-FLOUR-RSV,REC-FLOUR-NV)
           LIGHT-TO-SPACE       =0.9            $DOE-2 DEFAULT(0 TO 1)FOR SUS-FLUOR
           LIGHTING-W/SQFT      =1.27           $FROM MEASURED DATA
           EQUIP-SCHEDULE       = EQUIP-1
           EQUIPMENT-W/SQFT     = 0.74          $MEASURED DATA FROM TYPICAL(4th) FLOOR
           EQUIP-SENSIBLE       = 1             $DOE-2 DEFAULT(0 TO 1)
           EQUIP-LATENT         = 0             $DOE-2 DEFAULT(0 TO 1)
```

```
            INF-METHOD            = AIR-CHANGE    $DOE-2 DEFAULT=NONE(OR CRACK,RESIDENTIAL,S-G)
            AIR-CHANGES/HR        = 0             $HVAC ALWAYS ON
            INF-SCHEDULE          = INFIL-SCH     $ASSUMED
            FLOOR-WEIGHT          = 0             $DOE-2 DEFAULT (LB/SQ.FT),MEDIUM
$           WEIGHTING-FACTOR      =                UNUSED, ALTERNATE FOR FLOOR WEIGHT
            FURN-FRACTION         =  0.5          $UNUSED, USED FOR CWF METHOD
            FURNITURE-TYPE        =  LIGHT        $UNUSED, DOE-2 DEFAULT,USED FOR CWF METHOD
            FURN-WEIGHT           =  8     ..     $UNUSED, USED FOR CWF METHOD(LB/FT^2)

COMP-ROOM= SPACE-CONDITIONS
            PEOPLE-SCHEDULE       =OCCUPY-1
            AREA/PERSON           =275
            PEOPLE-HG-SENS        =230
            PEOPLE-HG-LAT         =190
            LIGHTING-SCHEDULE     =LIGHT-1
            LIGHTING-TYPE         =SUS-FLUOR
            LIGHT-TO-SPACE        =1
            LIGHTING-W/SQFT       =0
            EQUIP-SCHEDULE        =EQUIP-2
           $EQUIPMENT-W/SQFT      =1.3
            EQUIPMENT-KW          =52             $TOTAL 84KW-CRU(32KW)
            EQUIP-SENSIBLE        =1
            EQUIP-LATENT          =0
            INF-METHOD            =AIR-CHANGE
            AIR-CHANGES/HR        =0
            INF-SCHEDULE          =INFIL-SCH
            FLOOR-WEIGHT          = 0            $DOE-2 DEFAULT (LB/SQ.FT),MEDIUM
$           WEIGHTING-FACTOR      =               UNUSED, ALTERNATE FOR FLOOR WEIGHT
            FURN-FRACTION         = .5           $UNUSED, USED FOR CWF METHOD
            FURNITURE-TYPE        =LIGHT         $UNUSED, DOE-2 DEFAULT,USED FOR CWF METHOD
            FURN-WEIGHT           =8      ..     $UNUSED, USED FOR CWF METHOD(LB/FT^2)
```

…… SPACE DETAILES IN LOADS ARE OMITTED INTENTIONALLY TO REDUCE THE NEMBER OF PAGES ……

```
INPUT SYSTEMS
      INPUT-UNITS  = ENGLISH                   $DOE-2 DEFAULT VALUE
      OUTPUT-UNITS = ENGLISH  ..               $DOE-2 DEFAULT VALUE

SYSTEMS-REPORT
      VERIFICATION = (SV-A, SV-B)
$                     SV-A,                    SYSTEM DESIGN PARAMETERS
$                     SV-B,                    ZONE FAN DATA
           SUMMARY = (SS-D)                   $REPORTS TO BE PRINTED
$                     SS-D,                    PLANT MONTHLY LOADS SUMMARY
..

$EXTERIOR LIGHTS
 ELIGHT = SCHEDULE
 THRU DEC 31   (ALL) (1,24)  (1)
..

$DOMESTIC HOT WATER
 DHWSCH-1 = SCHEDULE
 THRU DEC 31
 (WD) (1,24)  (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.15,0.30,0.35,0.35,0.45,
               0.55,0.50,0.30,0.30,0.40,0.20,0.20,0.10,0.15,0.05,0.00,0.00)
 (SAT) (1,24) (0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.10,0.10,0.20,0.15,0.20,
               0.15,0.15,0.10,0.10,0.10,0.00,0.00,0.00,0.00,0.00,0.00,0.00)
 (SUN,HOL) (1,24) (0)
 ..

$FAN
 SCH202 = SCHEDULE                            $FAN SCHEDULE CAN HAVE THREE VALUES
 THRU DEC 31 (ALL) (1,24) = (1) ..            $1=ON,0=OFF BUT ALLOWED TO BE ON BY
                                              $NIGHT-CYLE-CTRL,-1=ABSOLUTELY OFF,
                                              $-999=OPTIMAL START/STOP TO MEET REQUIREMENTS
$FOR HEATING
 SCH207 = SCHEDULE           THRU DEC 31  (ALL) (1,24) = (71) ..

$FOR COOLING
 SCH208 = SCHEDULE           THRU DEC 31  (ALL) (1,24) = (71) ..

$FOR HEATING COIL SET. TEMP.
 H_COIL_SCH = SCHEDULE       THRU JUL 31  (ALL) (1,24) = (105)
                             THRU NOV 10  (ALL) (1,24) = (75)
                             THRU DEC 31  (ALL) (1,24) = (75) ..

$DESCRIPTION OF ZONE: LOWER-0
  LOWER-0 = ZONE
          ZONE-TYPE = CONDITIONED
          ZONE-REPORTS = NO                   $DOE-2 DEFAULT= YES
          SIZING-OPTION = ADJUST-LOADS        $DOE-2 DEFAULT= FROM LOAD

$ ZONE-CONTROL
          COOL-TEMP-SCH = SCH208
          DESIGN-HEAT-T = 71                  $EQUAL TO THE SUMMER SETPOINT (F)
          DESIGN-COOL-T = 71                  $EQUAL TO THE WINTER SETPOINT (F)
          THERMOSTAT-TYPE = PROPORTIONAL      $DOE-2 DEFAULT
          THROTTLING-RANGE = 4                $DOE-2 DEFAULT= 2F

..                                            $END OF ZONE COMMAND
```

```
PARKING        = ZONE       ZONE-TYPE=UNCONDITIONED
                            SIZING-OPTION=ADJUST-LOADS  ..
LOWER-0-PLM    = ZONE       ZONE-TYPE= PLENUM
                            SIZING-OPTION=ADJUST-LOADS  ..
LOWER-1        = ZONE       ZONE-TYPE = CONDITIONED
                            ZONE-REPORTS = NO             $DOE-2 DEFAULT= YES
                            SIZING-OPTION = ADJUST-LOADS  $DOE-2 DEFAULT= FROM LOAD
                            HEAT-TEMP-SCH = SCH207
                            COOL-TEMP-SCH = SCH208
                            DESIGN-HEAT-T = 71            $EQUAL TO THE SUMMER SETPOINT (F)
                            DESIGN-COOL-T = 71            $EQUAL TO THE WINTER SETPOINT (F)
                            THERMOSTAT-TYPE = PROPORTIONAL  $DOE-2 DEFAULT
                            THROTTLING-RANGE = 4          $DOE-2 DEFAULT= 2F
                           $OA-CFM/PER = 20
                           $ASSIGNED-CFM = 5100           DESIGN VALUE= 5100
                           $OUTSIDE-AIR-CFM = 900
                                  ..
LOWER-2        = ZONE       LIKE LOWER-1  ..
                           $ASSIGNED-CFM = 16500          AS DESIGNED
                           $OUTSIDE-AIR-CFM = 4500  ..    AS DESIGNED
LOWER-3        = ZONE       ZONE-TYPE = CONDITIONED       $NO HEATING COIL
                            ZONE-REPORTS = NO             $DOE-2 DEFAULT= YES
                            THERMOSTAT-TYPE = REVERSE-ACTION
                            THROTTLING-RANGE = 4          $DOE-2 DEFAULT= 2F
                            SIZING-OPTION = ADJUST-LOADS  $DOE-2 DEFAULT= FROM LOAD
                            COOL-TEMP-SCH = SCH208
                            DESIGN-HEAT-T = 71            $EQUAL TO THE SUMMER SETPOINT (F)
                            DESIGN-COOL-T = 71            $EQUAL TO THE WINTER SETPOINT (F)
                            ..
LOWER-4        = ZONE       LIKE LOWER-3
                            ..
LOWER-5        = ZONE       LIKE LOWER-3
                            ..
LOWER-5-PLM    = ZONE       LIKE LOWER-0-PLM  ..
LOWER-6        = ZONE       LIKE LOWER-3
                            ..
LOWER-7        = ZONE       LIKE LOWER-1   ..
                           $ASSIGNED-CFM = 15600
                           $OUTSIDE-AIR-CFM = 3845  ..

CORE-1         = ZONE       ZONE-TYPE = CONDITIONED
                            ZONE-REPORTS = NO             $DOE-2 DEFAULT= YES
                            SIZING-OPTION = ADJUST-LOADS  $DOE-2 DEFAULT= FROM LOAD
                            THERMOSTAT-TYPE = REVERSE-ACTION
                            HEAT-TEMP-SCH = SCH207
                            COOL-TEMP-SCH = SCH208
                            DESIGN-HEAT-T = 71            $EQUAL TO THE SUMMER SETPOINT (F)
                            DESIGN-COOL-T = 71 ..         $EQUAL TO THE WINTER SETPOINT (F)
                           $OA-CFM/PER = 50  ..
CORE-1-PLM     = ZONE       LIKE LOWER-0-PLM
                            ZONE-TYPE=PLENUM  ..
WEST-1         = ZONE       LIKE CORE-1   ..
EAST-1         = ZONE       LIKE CORE-1   ..
NORTH-1        = ZONE       LIKE CORE-1   ..
LOBBY-1        = ZONE       LIKE CORE-1   ..
SOUTH-1        = ZONE       LIKE CORE-1   ..
CORE1-2        = ZONE       LIKE CORE-1   ..
CORE1-2-PLM    = ZONE       LIKE CORE-1-PLM  ..
```

```
CORE1-3        = ZONE      LIKE CORE-1   ..
SOUTH1-2       = ZONE      LIKE CORE-1   ..
SOUTH1-3       = ZONE      LIKE CORE-1   ..
SOUTH1-4       = ZONE      LIKE CORE-1   ..
EAST1-2        = ZONE      LIKE CORE-1   ..
NORTH1-2       = ZONE      LIKE CORE-1   ..
MEETING-1      = ZONE      LIKE LOWER-1  ..
                          $ASSIGNED-CFM = 12275
                          $OUTSIDE-AIR-CFM = 3854 ..
CORE-2         = ZONE      LIKE CORE-1   ..
CORE-2-PLM     = ZONE      LIKE CORE-1-PLM  ..
WEST-2         = ZONE      LIKE CORE-1   ..
SOUTH-2        = ZONE      LIKE CORE-1   ..
EAST-2         = ZONE      LIKE CORE-1   ..
NORTH-2        = ZONE      LIKE CORE-1   ..
CORE2-2        = ZONE      LIKE CORE-1   ..
CORE2-2-PLM    = ZONE      LIKE CORE-1-PLM  ..
CORE2-3        = ZONE      LIKE CORE-1   ..
CORE2-4        = ZONE      LIKE CORE-1   ..
WEST2-2        = ZONE      LIKE CORE-1   ..
SOUTH2-2       = ZONE      LIKE CORE-1   ..
SOUTH2-3       = ZONE      LIKE CORE-1   ..
SOUTH2-4       = ZONE      LIKE CORE-1   ..
SOUTH2-5       = ZONE      LIKE CORE-1   ..
SOUTH2-6       = ZONE      LIKE CORE-1   ..
EAST2-2        = ZONE      LIKE CORE-1   ..
NORTH2-2       = ZONE      LIKE CORE-1   ..
CORE-3         = ZONE      LIKE CORE-1   ..
CORE-3-PLM     = ZONE      LIKE CORE-1-PLM  ..
WEST-3         = ZONE      LIKE CORE-1   ..
SOUTH-3        = ZONE      LIKE CORE-1   ..
EAST-3         = ZONE      LIKE CORE-1   ..
NORTH-3        = ZONE      LIKE CORE-1   ..
CORE3-2        = ZONE      LIKE CORE-1   ..
CORE3-2-PLM    = ZONE      LIKE CORE-1-PLM ..
CORE3-3        = ZONE      LIKE CORE-1   ..
CORE3-4        = ZONE      LIKE CORE-1   ..
WEST3-2        = ZONE      LIKE CORE-1   ..
SOUTH3-2       = ZONE      LIKE CORE-1   ..
SOUTH3-3       = ZONE      LIKE CORE-1   ..
SOUTH3-4       = ZONE      LIKE CORE-1   ..
SOUTH3-5       = ZONE      LIKE CORE-1   ..
SOUTH3-6       = ZONE      LIKE CORE-1   ..
EAST3-2        = ZONE      LIKE CORE-1   ..
NORTH3-2       = ZONE      LIKE CORE-1   ..
CORE-4         = ZONE      LIKE CORE-1   ..
CORE-4-PLM     = ZONE      LIKE CORE-1-PLM  ..
WEST-4         = ZONE      LIKE CORE-1   ..
SOUTH-4        = ZONE      LIKE CORE-1   ..
EAST-4         = ZONE      LIKE CORE-1   ..
NORTH-4        = ZONE      LIKE CORE-1   ..
CORE4-2        = ZONE      LIKE CORE-1   ..
CORE4-2-PLM    = ZONE      LIKE CORE-1-PLM  ..
CORE4-3        = ZONE      LIKE CORE-1   ..
CORE4-4        = ZONE      LIKE CORE-1   ..
WEST4-2        = ZONE      LIKE CORE-1   ..
SOUTH4-2       = ZONE      LIKE CORE-1   ..
SOUTH4-3       = ZONE      LIKE CORE-1   ..
```

```
SOUTH4-4       = ZONE      LIKE CORE-1   ..
SOUTH4-5       = ZONE      LIKE CORE-1   ..
SOUTH4-6       = ZONE      LIKE CORE-1   ..
EAST4-2        = ZONE      LIKE CORE-1   ..
NORTH4-2       = ZONE      LIKE CORE-1   ..
CORE-5         = ZONE      LIKE CORE-1   ..
CORE-5-PLM     = ZONE      LIKE CORE-1-PLM  ..
WEST-5         = ZONE      LIKE CORE-1   ..
SOUTH-5        = ZONE      LIKE CORE-1   ..
EAST-5         = ZONE      LIKE CORE-1   ..
NORTH-5        = ZONE      LIKE CORE-1   ..
CORE5-2        = ZONE      LIKE CORE-1   ..
CORE5-2-PLM    = ZONE      LIKE CORE-1-PLM  ..
CORE5-3        = ZONE      LIKE CORE-1   ..
CORE5-4        = ZONE      LIKE CORE-1   ..
WEST5-2        = ZONE      LIKE CORE-1   ..
SOUTH5-2       = ZONE      LIKE CORE-1   ..
SOUTH5-3       = ZONE      LIKE CORE-1   ..
SOUTH5-4       = ZONE      LIKE CORE-1   ..
SOUTH5-5       = ZONE      LIKE CORE-1   ..
SOUTH5-6       = ZONE      LIKE CORE-1   ..
EAST5-2        = ZONE      LIKE CORE-1   ..
NORTH5-2       = ZONE      LIKE CORE-1   ..
CORE-6         = ZONE      LIKE CORE-1   ..
CORE-6-PLM     = ZONE      LIKE CORE-1-PLM ..
WEST-6         = ZONE      LIKE CORE-1   ..
SOUTH-6        = ZONE      LIKE CORE-1   ..
EAST-6         = ZONE      LIKE CORE-1   ..
NORTH-6        = ZONE      LIKE CORE-1   ..
PENTH-W1       = ZONE      LIKE CORE-1-PLM  ..
PENTH-W2       = ZONE      LIKE CORE-1-PLM  ..
PENTH-S1       = ZONE      LIKE CORE-1-PLM  ..
PENTH-S2       = ZONE      LIKE CORE-1-PLM  ..

PSZ_1=   SYSTEM
                 SYSTEM-TYPE= PSZ
                 PLENUM-NAMES= (LOWER-0-PLM)
                 ZONE-NAMES= (LOWER-0, LOWER-0-PLM)
                 RETURN-AIR-PATH= PLENUM-ZONES
                 HEAT-SOURCE= ELECTRIC             $DOE-2 DEFAULT=GAS-FURNACE
                 HUMIDIFIER-TYPE= ELECTRIC         $UNUSED, NO HUMIDIFIER

$SYSTEM CONTROL
                 MAX-SUPPLY-T = 105                $90F, DOE-2 DEFAULT=105
                 MIN-SUPPLY-T = 55                   $52F, FROM EMCS DATA, DEFAULT=55
                 MAX-HUMIDITY = 60                 $HUMIDICATION CONTROL
                 MIN-HUMIDITY = 45                 $NO DEHUMIDICATION CONTROL

$SYSTEM AIR
                 OA-CONTROL = FIXED                $DOE-2 DEFAULT = TEMP
                 MIN-OUTSIDE-AIR= 0.1
                 DUCT-AIR-LOSS= 0.3                $UNUSED,DOE-2 DEFAULT
                $DUCT-DELTA-T= NONE                 UNUSED,DOE-2 DEFAULT

$SUPPLY FAN
                $SUPPLY-STATIC = 4.0                FROM SUPPLY-DELTA-T &SUPPLY-KW
                $SUPPLY-EFF = 0.4                   FROM SUPPLY-DELTA-T &SUPPLY-KW
                 SUPPLY-DELTA-T =1.815             $DEFAULT=1.815
```

```
                 SUPPLY-KW= 0.00087                 $6.786/7835.7=0.00087(KW/CFM)
                 FAN-SCHEDULE = SCH202
                 FAN-CONTROL = CONSTANT-VOLUME
                 SUPPLY-MECH-EFF = 0.4
                 MOTOR-PLACEMENT = IN-AIRFLOW       $DOE-2 DEFAULT
                 FAN-PLACEMENT = DRAW-THROUGH       $DOE-2 DEFAULT
                 MAX-FAN-RATIO = 1.1                $DOE-2 DEFAULT
                 MIN-FAN-RATIO = 0.3                $DOE-2 DEFAULT
                 NIGHT-CYCLE-CTRL = STAY-OFF
                $FAN-EIRFPLR=                        UNUSED,ONLY IF FAN-CONTROL=FAN-EIR-FPLR

$SYSTEM TERMINAL
                 MIN-CFM-RATIO =1                   $CONSTANT VOLUME SYSTEM
                $REHEAT-DELTA-T = 50                 UNUSED, NO HEATING COIL

$SYSTEM EQUIPMENT
                 COOLING-EIR= 0.36                  $ DOE-2 DEFAULT (BTU/BTU)
                     COIL-BF = .19                  $ DOE-2 DEFAULT =0.19
                   ..
SZRH_1=   SYSTEM
                 SYSTEM-TYPE= SZRH
                 ZONE-NAMES= (LOWER-3, LOWER-4, LOWER-5, LOWER-6,
                              LOWER-5-PLM,PARKING)
                 RETURN-AIR-PATH=DUCT
                 HEAT-SOURCE= HOT-WATER             $DOE-2 DEFAULT
                $PREHEAT-SOURCE= HOT-WATER           UNUSED, DOE-2 DEFAULT
                $ZONE-HEAT-SOURCE= HOT-WATER         UNUSED, DOE-2 DEFAULT
                $BASEBOARD-SOURCE= HOT-WATER         UNUSED, DOE-2 DEFAULT
                $HUMIDIFIER-TYPE= HOT-WATER          UNUSED, DOE-2 DEFAULT

$SYSTEM CONTROL
                 MAX-SUPPLY-T = 105                 $90 F, DOE-2 DEFAULT=105
                 MIN-SUPPLY-T = 55                  $DOE-2 DEFAULT
                 PREHEAT-T= 45                      $55F, DOE-2 DEFAULT = 45 F
                $MAX-HUMIDITY=                       UNUSED, NO HUMIDICATION CONTROL
                $MIN-HUMIDITY=                       UNUSED, NO DEHUMIDICATION CONTROL
                $ECONO-LIMIT-T                       UNUSED
                $ECONO-LOW-LIMIT                     UNUSED
                $BASEDBOARD-SCH                      UNUSED
$SYSTEM AIR
                 OA-CONTROL = FIXED                 $DOE-2 DEFAULT = TEMP
                 MIN-OUTSIDE-AIR= 0.1               $VAV UNIT
                $MIN-AIR-SCH =                       UNUSED
                $MAX-OA-FRACTION= 1                  UNUSED,DOE-2 DEFAULT
                $SUPPLY-CFM=                         UNUSED
                $RETURN-CFM=                         UNUSED
                $RECOVERY-EFF=                       UNUSED
                 DUCT-AIR-LOSS= 0.3                 $UNUSED,DOE-2 DEFAULT
                $DUCT-DELTA-T= NONE                  UNUSED,DOE-2 DEFAULT

$SUPPLY FAN
                $SUPPLY-STATIC = 4.0                 FROM SUPPLY-DELTA-T &SUPPLY-KW
                $SUPPLY-EFF = 0.9                    FROM SUPPLY-DELTA-T &SUPPLY-KW
                 SUPPLY-DELTA-T =2.42               $DEFAULT= 2.42 F
                 SUPPLY-KW= 0.00159                 $7.75/4862.5=0.00159(KW/CFM)
                 FAN-SCHEDULE = SCH202
                 FAN-CONTROL = SPEED
                 SUPPLY-MECH-EFF = 0.35
```

```
                MOTOR-PLACEMENT = IN-AIRFLOW        $DOE-2 DEFAULT
                FAN-PLACEMENT = DRAW-THROUGH        $DOE-2 DEFAULT
                MAX-FAN-RATIO= 1.1                  $DOE-2 DEFAULT
                MIN-FAN-RATIO= 0.3                  $DOE-2 DEFAULT
                NIGHT-CYCLE-CTRL = STAY-OFF

$SYSTEM TERMINAL
                MIN-CFM-RATIO = 0.6                 $SINGLE DUCT VARIABLE VOLUME SYSTEM
               $REHEAT-DELTA-T = 50                 UNUSED, NO REHEAT SYSTEM

$SYSTEM EQUIPMENT
                COIL-BF = .037                      $DOE-2 DEFAULT =0.037
               $COIL-BF-FCFM = SDL-C38               DOE-2 STANDARD CURVE FOR CENTRAL SYSTEMS
               $COIL-BF-FT   = SDL-C48               DOE-2 STANDARD CURVE FOR CENTRAL SYSTEMS
               $COIL-BF-FPLR = SDL-C161              DOE-2 STANDARD CURVE FOR CENTRAL SYSTEMS
                    ..

SZRH_2=   SYSTEM
                SYSTEM-TYPE= SZRH
                ZONE-NAMES= (LOWER-2, LOWER-7)
                RETURN-AIR-PATH=DUCT
                HEAT-SOURCE= HOT-WATER              $DOE-2 DEFAULT
                PREHEAT-SOURCE= HOT-WATER           $DOE-2 DEFAULT
                HUMIDIFIER-TYPE= ELECTRIC           $ELECTRIC STEAM

$SYSTEM CONTROL
                MAX-SUPPLY-T = 105                  $95F, DOE-2 DEFAULT=105
                MIN-SUPPLY-T = 55                   $DOE-2 DEFAULT
                PREHEAT-T= 45                       $55F, DOE-2 DEFAULT =45
                MAX-HUMIDITY= 60                    $HUMIDICATION CONTROL
                MIN-HUMIDITY= 40                    $DEHUMIDICATION CONTROL

$SYSTEM AIR
                OA-CONTROL = FIXED                  $ASSIGNED CFM IN ZONE LEVEL
                MIN-OUTSIDE-AIR= 0.1
               $MIN-AIR-SCH = SCH209
                DUCT-AIR-LOSS= 0.3

$SUPPLY FAN
               $SUPPLY-STATIC = 4.0                  FROM SUPPLY-DELTA-T &SUPPLY-KW
               $SUPPLY-EFF = 0.9                     FROM SUPPLY-DELTA-T &SUPPLY-KW
                SUPPLY-DELTA-T =2.42                $DEFAULT= 2.42 F
                SUPPLY-KW= 0.00125                  $20/16050=0.00125(KW/CFM)
                FAN-SCHEDULE = SCH202
                FAN-CONTROL = CONSTANT-VOLUME
                SUPPLY-MECH-EFF = 0.4
                MOTOR-PLACEMENT = IN-AIRFLOW        $DOE-2 DEFAULT
                FAN-PLACEMENT = DRAW-THROUGH        $DOE-2 DEFAULT
                NIGHT-CYCLE-CTRL = STAY-OFF
               $FAN-EIRFPLR=                         UNUSED,ONLY IF FAN-CONTROL=FAN-EIR-FPLR

$SYSTEM TERMINAL
                MIN-CFM-RATIO =1                    $CONSTANT VOLUME SYSTEM
                REHEAT-DELTA-T = 50

$SYSTEM EQUIPMENT
                COIL-BF = .037                    $DOE-2 DEFAULT =0.037
               $COIL-BF-FCFM = SDL-C38             DOE-2 STANDARD CURVE FOR CENTRAL SYSTEMS
```

```
              $COIL-BF-FT   = SDL-C48              DOE-2 STANDARD CURVE FOR CENTRAL SYSTEMS
              $COIL-BF-FPLR = SDL-C161             DOE-2 STANDARD CURVE FOR CENTRAL SYSTEMS
              ..

MULTI_1=  SYSTEM
               SYSTEM-TYPE= MZS
               ZONE-NAMES= (LOWER-1,MEETING-1)
               RETURN-AIR-PATH=DUCT
               HEAT-SOURCE= HOT-WATER            $DOE-2 DEFAULT
               PREHEAT-SOURCE= HOT-WATER         $DOE-2 DEFAULT
              $ZONE-HEAT-SOURCE= HOT-WATER        UNUSED, DOE-2 DEFAULT
              $BASEBOARD-SOURCE= HOT-WATER        UNUSED, DOE-2 DEFAULT
              $HUMIDIFIER-TYPE= HOT-WATER         UNUSED, DOE-2 DEFAULT

$SYSTEM CONTROL
               MAX-SUPPLY-T = 105                $90F, DOE-2 DEFAULT = 105
               MIN-SUPPLY-T = 55                 $53F, DOE-2 DEFAULT = 55
               PREHEAT-T= 45                     $55F, DOE-2 DEFAULT =45
$SYSTEM AIR
               OA-CONTROL = FIXED
               MIN-OUTSIDE-AIR= 0.1              $ASSIGNED CFM IN ZONE LEVEL
              $MIN-AIR-SCH =SCH209                UNUSED
               DUCT-AIR-LOSS= 0.3                $UNUSED,DOE-2 DEFAULT
              $DUCT-DELTA-T= NONE                 UNUSED,DOE-2 DEFAULT

$SUPPLY FAN
              $SUPPLY-STATIC = 4.0                FROM SUPPLY-DELTA-T &SUPPLY-KW
              $SUPPLY-EFF = 0.9                   FROM SUPPLY-DELTA-T &SUPPLY-KW
               SUPPLY-DELTA-T =2.723             $DEFAULT= 2.723 F
               SUPPLY-KW= 0.00122                $10/8187.5=0.00122(KW/CFM)
               FAN-SCHEDULE = SCH202
               FAN-CONTROL = CONSTANT-VOLUME
               SUPPLY-MECH-EFF = 0.45
               MOTOR-PLACEMENT = IN-AIRFLOW      $DOE-2 DEFAULT
               NIGHT-CYCLE-CTRL = STAY-OFF

$SYSTEM TERMINAL
               MIN-CFM-RATIO =1                  $CONSTANT VOLUME SYSTEM
               ..

DDVAV_0=  SYSTEM
               SYSTEM-TYPE= DDS
               RETURN-AIR-PATH= PLENUM-ZONES
               HEAT-SOURCE= HOT-WATER            $DOE-2 DEFAULT
               PREHEAT-SOURCE= HOT-WATER         $DOE-2 DEFAULT
               PLENUM-NAMES= (CORE-1-PLM )
               ZONE-NAMES=  (CORE-1,WEST-1,EAST-1,NORTH-1,
                             LOBBY-1,SOUTH-1, CORE-1-PLM )
$SYSTEM CONTROL
               MAX-SUPPLY-T     = 105            $90F, DOE-2 DEFAULT=105F
               MIN-SUPPLY-T     = 55
              $HEAT-SET-T       = 105             DOE-2 DEFAULT=105, (DEG F)
               COOL-SET-T       = 55             $DOE-2 DEFAULT =55F
               PREHEAT-T        = 45             $55F,DOE-2 DEFAULT, (DEG F)
               HEAT-CONTROL     = SCHEDULED
               COOL-CONTROL     = CONSTANT       $DOE-2 DEFAULT
               HEAT-SET-SCH     = H_COIL_SCH     $UNUSED, ONLY IF HEAT-CONTROL = SCHEDULE
```

```
$SYSTEM AIR
$          SUPPLY-CFM =                           UNUSED, FROM ZONE AIR AND LOAD
$          RETURN-CFM =                           UNUSED, SUPPLY-CFM MINUS EXHAUST-CFM OR 0
           OA-CONTROL = FIXED
           MIN-OUTSIDE-AIR= 0.1                  $VAV UNIT
           DUCT-AIR-LOSS = 0.3                   $UNUSED, DOE-2 DEFAULT(0 TO 1),  NONE

$SUPPLY FAN
           $SUPPLY-STATIC = 2.5                   FROM SUPPLY-DELTA-T &SUPPLY-KW
           $SUPPLY-EFF = 0.9                      FROM SUPPLY-DELTA-T &SUPPLY-KW
            SUPPLY-DELTA-T =3.37                 $DEFAULT= 3.37 F
            SUPPLY-KW= 0.00105                   $20/18970= 0.00109 (KW/CFM)
            FAN-SCHEDULE = SCH202
            FAN-CONTROL = SPEED
            SUPPLY-MECH-EFF = 0.51
            MOTOR-PLACEMENT = IN-AIRFLOW         $DOE-2 DEFAULT
            NIGHT-CYCLE-CTRL = STAY-OFF

$ SYSTEM TERMINAL
            MIN-CFM-RATIO =0.6                   $ FOR VARIABLE VOLUME SYSTEM

..
DDVAV_1= SYSTEM  LIKE DDVAV_0
                 PLENUM-NAMES= (CORE1-2-PLM)
                 ZONE-NAMES=  (CORE1-2,CORE1-3,SOUTH1-2, SOUTH1-3,
                                SOUTH1-4,EAST1-2,NORTH1-2, CORE1-2-PLM )  ..
DDVAV_2= SYSTEM  LIKE DDVAV_0
                 PLENUM-NAMES= (CORE-2-PLM, CORE2-2-PLM)
                 ZONE-NAMES=  (CORE-2, WEST-2,SOUTH-2, EAST-2, NORTH-2,
                                CORE2-2, CORE2-3, CORE2-4,
                                WEST2-2, SOUTH2-2, SOUTH2-3, SOUTH2-4,
                                SOUTH2-5, SOUTH2-6, EAST2-2, NORTH2-2,
                                CORE-2-PLM, CORE2-2-PLM)  ..
DDVAV_3= SYSTEM  LIKE DDVAV_0
                 PLENUM-NAMES= (CORE-3-PLM, CORE3-2-PLM)
                 ZONE-NAMES=  (CORE-3, WEST-3,SOUTH-3, EAST-3, NORTH-3,
                               CORE3-2, CORE3-3, CORE3-4,
                               WEST3-2, SOUTH3-2, SOUTH3-3, SOUTH3-4,
                               SOUTH3-5, SOUTH3-6, EAST3-2, NORTH3-2,
                               CORE-3-PLM, CORE3-2-PLM)  ..
DDVAV_4= SYSTEM  LIKE DDVAV_0
                 PLENUM-NAMES= (CORE-4-PLM, CORE4-2-PLM)
                 ZONE-NAMES=   (CORE-4, WEST-4, SOUTH-4, EAST-4, NORTH-4,
                                CORE4-2, CORE4-3, CORE4-4,
                                WEST4-2, SOUTH4-2, SOUTH4-3,
                                SOUTH4-4, SOUTH4-5, SOUTH4-6, EAST4-2,
                                NORTH4-2, CORE-4-PLM, CORE4-2-PLM )  ..
DDVAV_5= SYSTEM  LIKE DDVAV_0
                 PLENUM-NAMES= (CORE-5-PLM, CORE5-2-PLM, CORE-6-PLM)
                 ZONE-NAMES=   (CORE-5, WEST-5, SOUTH-5, EAST-5, NORTH-5,
                                CORE5-2,  CORE5-3, CORE5-4,
                                WEST5-2, SOUTH5-2, SOUTH5-3, SOUTH5-4,
                                SOUTH5-5, SOUTH5-6, EAST5-2, NORTH5-2,
                                CORE-6,  WEST-6, SOUTH-6,
                                EAST-6, NORTH-6, PENTH-W1, PENTH-W2,
                                PENTH-S1, PENTH-S2,
                                CORE-5-PLM, CORE5-2-PLM, CORE-6-PLM)  ..
```

```
PLANT1 = PLANT-ASSIGNMENT
SYSTEM-NAMES =(PSZ_1, SZRH_1, SZRH_2, MULTI_1, DDVAV_0,
               DDVAV_1, DDVAV_2, DDVAV_3, DDVAV_4, DDVAV_5)
            PLANT-REPORTS = YES                    $DEFAULT

$ EXTERIOR LIGHTS
            EXT-LIGHT-KW =  72.818                 $KW (8 + 64.818)
            EXT-LIGHT-SCH = ELIGHT                 $SUNRISE AND SUN SET (12KW), CONSTANT (12KW)
$ DOMESTRIC HOT WATER
            DHW-TYPE = ELECTRIC
            DHW-SUPPLY-T = 110                     $IECC 2001(402.1.3.7)=120
            DHW-LOSS-COEF = .03                    $DOE-2 DEFAULT,(0 TO 1)
            DHW-GAL/MIN = 4.22
            DHW-SCH = DHWSCH-1
..

$ SYSTEMS HOURLY-REPORT

$S-SCH1 = SCHEDULE
$          THRU AUG 30 (ALL) (1,24) VALUES=(1)
$            THRU AUG 31 (ALL) (1,24) VALUES=(1)
$            THRU DEC 31 (ALL) (1,24) VALUES=(1) ..

$SLRB-1   = REPORT-BLOCK
$          VARIABLE-TYPE= SZRH_1
$          VARIABLE-LIST=(1,2,3,4,39)  ..
                         $1:  HEATING COIL AIR TEMP - HOT DECK TEMP. (F)
                         $2:  COOLING COIL AIR TEMP. -COLD DECK TEMP.(F)
                         $3:  TEMP. OF AIR ENTERING COIL (F)
                         $4:  RETURN AIR TEMP.(F)
                         $39: RATIO OF OUTSIDE AIR FLOW
$SLRB-2   = REPORT-BLOCK
$          VARIABLE-TYPE= SZRH_2
$          VARIABLE-LIST=(1,2,3,4,39)  ..
                         $1:  HEATING COIL AIR TEMP - HOT DECK TEMP. (F)
                         $2:  COOLING COIL AIR TEMP. -COLD DECK TEMP.(F)
                         $3:  TEMP. OF AIR ENTERING COIL (F)
                         $4:  RETURN AIR TEMP.(F)
                         $39: RATIO OF OUTSIDE AIR FLOW

$SLRB-3   = REPORT-BLOCK
$          VARIABLE-TYPE= DDVAV_4
$          VARIABLE-LIST=(1,2,3,4,39)  ..
                         $1:  HEATING COIL AIR TEMP. - HOT DECK TEMP. (F)
                         $2:  COOLING COIL AIR TEMP. - COLD DECK TEMP.(F)
                         $3:  TEMP. OF AIR ENTERING COIL (F)
                         $4:  RETURN AIR TEMP.(F)
                         $39: RATIO OF OUTSIDE AIR FLOW

$SLRB-4   = REPORT-BLOCK
$          VARIABLE-TYPE= MULT_1
$          VARIABLE-LIST=(1,2,3,4,39)  ..
                         $1:  HEATING COIL AIR TEMP. - HOT DECK TEMP. (F)
                         $2:  COOLING COIL AIR TEMP. - COLD DECK TEMP.(F)
                         $3:  TEMP. OF AIR ENTERING COIL (F)
                         $4:  RETURN AIR TEMP.(F)
                         $39: RATIO OF OUTSIDE AIR FLOW
```

```
$SLRB-5   = REPORT-BLOCK
$          VARIABLE-TYPE= PLANT1
$          VARIABLE-LIST=(54,55) ..
                        $54:BOILER SUPPLY TEMP. SETPOINT (F)
                        $55:ESTIMATED BOILER SUPPLY TEMP.(F)
$SREP-1   = HOURLY-REPORT
$          REPORT-SCHEDULE=S-SCH1
$          REPORT-BLOCK=(SLRB-5) ..

END   ..
COMPUTE SYSTEMS  ..



INPUT PLANT
       INPUT-UNITS  = ENGLISH                  $DOE-2 DEFAULT
       OUTPUT-UNITS = ENGLISH  ..              $DOE-2 DEFAULT

PLANT-REPORT

   VERIFICATION  = (PV-A)
$                  PV-A,                        EQUIPMENT SIZES

        SUMMARY = (BEPS,PS-C,PS-E)
$                  PS-C,                        EQUIPMENT PART LOAD OPERATION
$                  PS-E,                        MONTHLY ENERGY END USE SUMMARY
$                  BEPS,                        BUILDING ENERGY PERFORMANCE SUMMARY
$                                               (UTILITY UNITS)
                      ..                       $END OF PLANT REPORT COMMAND

$ PLANT-ASSIGNMENT
       PLANT1 = PLANT-ASSIGNMENT  ..

$ HERM-CENT-CHILLER CURVE-FITS
  CH_CAP_FT = CURVE-FIT
        TYPE = BI-QUADRATIC
        COEF (-1.742040, 0.029292, -0.000067, 0.048054, -0.000291, -0.000106) ..
  CH_EIR_FP = CURVE-FIT
        TYPE = QUADRATIC
          COEF (0.222903, 0.313387, 0.463710) ..
  CH_EIR_FT = CURVE-FIT
        TYPE = BI-QUADRATIC
        COEF (3.117500, -0.109236, 0.001389, 0.003750, 0.000150, -0.000375) ..

$ FOR DOMESTIC HOT WATER
        DHW1 = PLANT-EQUIPMENT
        TYPE = ELEC-DHW-HEATER   SIZE= -999  ..

$ FOR ELECTRIC CHILLER #1
  CHILLER0_0 = PLANT-EQUIPMENT
        TYPE = HERM-CENT-CHLR
        SIZE = 5.58                           $FROM 465 TONS OF CHILLER(MBTU/HR)
$                                              (-999=SIZING ACCORDING TO LOADS)

        INSTALLED-NUMBER = 2
        MAX-NUMBER-AVAILABLE = 2
..
```

```
  CHILLER0_1 = PLANT-EQUIPMENT
        TYPE = HERM-CENT-CHLR
        SIZE = 5.58                           $FROM 465 TONS OF CHILLER(MBTU/HR)
$                                              (-999=SIZING ACCORDING TO LOADS)

        INSTALLED-NUMBER = 1
        MAX-NUMBER-AVAILABLE = 1
..

$PART LOAD INFO. FOR HERM-CENT-CHLR CHILLER
 PART-LOAD-RATIO
     TYPE = HERM-CENT-CHLR
     ELEC-INPUT-RATIO = 0.1547               $0.14505, DEFAULT=0.2 FOR HERM-CENT-CHLR
                                             $TRANE DATA 0.1547(0.544 KW/TON; COP=6.46)
     MIN-RATIO = 0.2                         $DEFAULT =0.1 FOR HERM-CENT-CHLR
     MAX-RATIO = 1                           $DEFAULT =1 FOR HERM-CENT-CHLR
     OPERATING-RATIO = 0.8                   $DEFAULT =0.8 FOR HERM-CENT-CHLR
..

$HOT WATER BOILER #1
     BOILER0_0 = PLANT-EQUIPMENT
     TYPE = HW-BOILER
     SIZE = 4.2                              $MILLION BTU/H
     INSTALLED-NUMBER = 1
     MAX-NUMBER-AVAILABLE = 1  ..

$ PART LOAD INFO. FOR FUEL HOT WATER BOILER #1
  PART-LOAD-RATIO
     TYPE = HW-BOILER
     ELEC-INPUT-RATIO = 0.022
     MIN-RATIO = .33                         $DEFAULT
     MAX-RATIO = 2  ..                       $DEFAULT

$ COOLING TOWER

TOWER1 = PLANT-EQUIPMENT
    TYPE = OPEN-TWR
    SIZE = 12
    INSTALLED-NUMBER = 2
    MAX-NUMBER-AVAILABLE = 2  ..

PART-LOAD-RATIO
    TYPE = OPEN-TWR
    ELEC-INPUT-RATIO = 0.00455  ..           $DETERMINED USING DESIGN DATA

PLANT-PARAMETERS

$ FOR HOT WATER PLANT BOILER
  BOILER-CONTROL= DEMAND-ONLY                $DEFAULT = DEMAND ONLY
  HW-BOILER-HIR  = 1.19
 $E-HW-BOILER-LOSS = 0.02                     UNUSED, DEFAULT =0.02

$ FOR DOMESTIC HOT WATER HEATER
  DHW-HIR = 1.39                             $DEFAULT( 0 TO 3)

$ FOR HERM-CENT-CHLR CHILLER

  PLANT-SIZING-BY= DD-IF-PRESENT        $DEFAULT(OR WEATHER)
```

```
  CHILLER-CONTROL= DEMAND-ONLY               $DEFAULT = DEMAND ONLY
  HERM-CENT-COND-TYPE = TOWER                $DEFAULT = TOWER
  HERM-CENT-COND-PWR = 0.3                   $DEFAULT = 0.3
  HERM-CENT-UNL-RAT = 0.1                    $DEFAULT = 0.1

  COMP-TO-TWR-WTR = 3                        $DAFAULT = 3 GAL/TON  AS DESIGNED
  MIN-COND-AIR-T = 65                        $DAFAULT = 65F
  CHILL-WTR-T = 44                           $DEFAULT = 44F
                                             $FROM THE MEASURED CHILLED WATER SUP TEMP.
  CHILL-WTR-THROTTLE = 2.5                   $DEFAULT = 2.5F

$TOWER
  TWR-DESIGN-WETBULB = 80                    $DEFAULT= 78F, AS DESIGNED
  TWR-DESIGN-APPROACH = 7                    $DFAULT = 7 F
  TWR-DESIGN-RANGE = 10                      $DFAULT = 10F
  TWR-SETPT-CTRL = FIXED                     $DEFAULT= FIXED
  TWR-SETPT-T = 80                           $DEFAULT= 90F, MEASURED CONDENSER RET TEMP.
  TWR-THROTTLE = 5                           $DEFAULT= 5F , MEASURED DATA
  MIN-TWR-WTR-T = 66                         $DEFAULT= 66F
  TWR-RESET-RATIO = 0.29                     $DEFAULT= 0.29
  TWR-CELL-CTRL = MIN-CELLS                  $DEFAULT= MIN-CELLS
  TWR-CAP-CTRL = VARIABLE-SPEED-FAN          $DEFAULT= ONE-SPEED-FAN
  TWR-MIN-FAN-SPEED = 0.4                    $DEFAULT= 0.4
  TWR-FAN-OFF-CFM =0.18                      $DEFAULT= 0.18
  TWR-PUMP-HEAD = 18                         $DEFAULT= 60FT, AS DESIGNED
  TWR-IMPELLER-EFF = 0.77                    $DEFAULT= 0.77
  TWR-MOTOR-EFF = 0.9                        $DEFAULT= 0.9
  DIRECT-COOL-MODE = NOT-AVAILABLE           $DEFAULT

$CHILLED WATER PUMP
 $CCIRC-ELEC-METER = M1                       UNUSED, DEFAULT,(OR M2,M3,M4,M5)
  CCIRC-PUMP-TYPE = VARIABLE-SPEED           $DEFAULT=FIXED-SPEED
  CCIRC-MOTOR-EFF = .9                       $DEFAULT= 0.9
  CCIRC-IMPELLER-EFF = .77                   $DEFAULT= 0.77
  CCIRC-HEAD = 50                            $DEFAULT= 60FT, AS DESIGNED
  CCIRC-DESIGN-T-DROP = 10                   $DEFAULT= 10 F
  CCIRC-LOSS = 0.01                          $DEFAULT= 0.01
  CCIRC-SIZE-OPT = INST-PLANT-EQUIP          $DEFAULT= SYSTEM PEAK

$HOT WATER PUMP
 $HCIRC-ELEC-METER = M1                       UNUSED, DEFAULT,(OR M2,M3,M4,M5)
  HCIRC-PUMP-TYPE = VARIABLE-SPEED           $DEFAULT=FIXED-SPEED
  HCIRC-MOTOR-EFF = .9                       $DEFAULT= 0.9
  HCIRC-IMPELLER-EFF = .77                   $DEFAULT= 0.77
  HCIRC-HEAD = 35                            $DEFAULT= 60 FT, AS DESIGNED
  HCIRC-DESIGN-T-DROP = 30                   $DEFAULT= 30 F
  HCIRC-LOSS = 0.01                          $DEFAULT= 0.01
  HCIRC-SIZE-OPT = INST-PLANT-EQUIP          $DEFAULT= SYSTEM PEAK
  HCIRC-MIN-PLR = 0.5                        $DEFAULT=0.5
 ..

$LOAD ASSIGNMENT
 LOAD-ASSG1 = LOAD-ASSIGNMENT
             TYPE= COOLING                   $ARBITRARY VALUE(OR COOLING,ELECTRICAL)
             OPERATION-MODE= RUN-NEEDED      $DEFAULT,(OR RUN-ALL)
             LOAD-RANGE= 11.16               $84% OF DESIGN LOAD(5.58 MBTU)
             PLANT-EQUIPMENT = CHILLER0_0
             NUMBER = 2
```

```
                PLANT-EQUIPMENT = CHILLER0_1
                NUMBER = 1
                LOAD-RANGE = 99
 ..

 LOAD-MANAGEMENT
 PRED-LOAD-RANGE = 99
 LOAD-ASSIGNMENT = ( DEFAULT, LOAD-ASSG1, DEFAULT)
 ..

$ PLANT HOURLY-REPORT

HR-SCH1 = SCHEDULE
          THRU DEC 31 (ALL) (1,24) VALUES=(1) ..

LRB-1   = REPORT-BLOCK
          VARIABLE-TYPE= PLANT
          VARIABLE-LIST=(3,8,9,10) ..
                         $1:HEATING LOAD FROM SYSTEMS
                         $2:COOLING LOAD FROM SYSTEMS
                         $3:ELEC LOAD FROM SYSTEM (KW)
                         $8:TOTAL HEATING LOAD TO BE MET BY PLANT(BTU/HR)
                         $9:TOTAL COOLING LOAD TO BE MET BY PLANT(BTU/HR)
                         $10:TOTAL ELEC. LOAD TO BE MET BY PLANT(BTU/HR)
                         $19:HOT WATER LOOP ELEC.
                         $21:COLD WATER LOOP ELEC
LRB-2   = REPORT-BLOCK
          VARIABLE-TYPE= HERM-CENT-CHLR
          VARIABLE-LIST=(12,13) ..
                         $12:ENTERING CONDENCER TEMP
                         $13:LEAVING CHILLED WATER TEMP

LRB-3   = REPORT-BLOCK
          VARIABLE-TYPE= END-USE
          VARIABLE-LIST=(6) ..
                           $ 6:COOLING ELECTRIC (KW)
REP-1   = HOURLY-REPORT
          REPORT-SCHEDULE=HR-SCH1
          REPORT-BLOCK=(LRB-1,LRB-2,LRB-3) ..

END  ..
COMPUTE PLANT  ..
STOP ..
```

VITA

NAME	Suwon Song
ADDRESS	7331-3 Taepyung 4, Sujung-Gu, Sungnam, Kyung-Gi, Korea
EMAIL	ssw1007@neo.tamu.edu

EDUCATION

Ph.D., 2006	Department of Architecture, Texas A&M University, College Station, Texas
M.S., 1997	Department of Architectural Engineering, SungKyunKwan University, Korea
B.S., 1994	Department of Architectural Engineering, SungKyunKwan University, Korea

EXPERIENCE

2001–2006	Graduate Research Assistant, Energy Systems Lab., Texas A&M University, College Station, Texas.
1997–1999	Research Associate, Building Technology Research Team, Samsung Everland Co., Korea
1995–1997	Research Assistant, Architectural Engineering, SungKyunKwan University, Korea
1994–1994	Research Associate, Construction Technology Research Center, Kunyoung Co., Korea
1989–1990	Army, Republic of Korea